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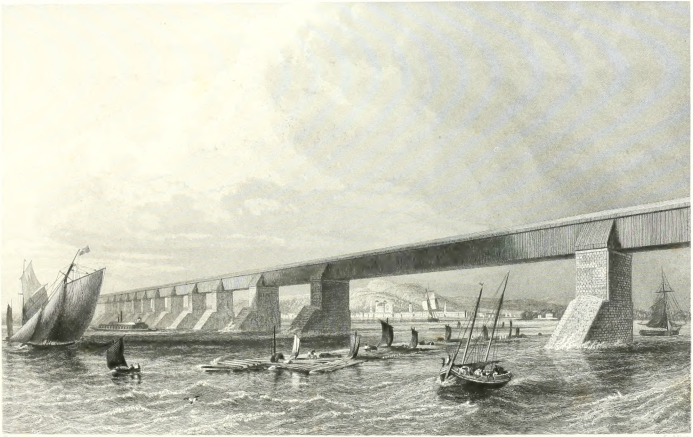

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CYCLOPÆDIA

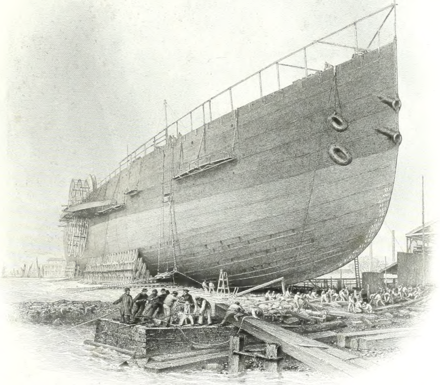
OF

USEFUL ARTS & MANUFACTURES.

EDITED BY

Charles Tomlinson,

LECTURER ON SCIENCE AT KING'S COLLEGE SCHOOL, LONDON



The Great Eastern.

JAMES S. VIRTUE, LONDON & NEW YORK.

CYCLOPÆDIA OF USEFUL ARTS,

Mechanical and Chemical,

MANUFACTURES, MINING, AND ENGINEERING.

IN THREE VOLUMES.

ILLUSTRATED BY

63 STEEL ENGRAVINGS AND 3063 WOOD ENGRAVINGS.

EDITED BY CHARLES TOMLINSON, F.C.S.,

LECTURER ON SCIENCE, KING'S COLLEGE SCHOOL, LONDON.

VOL. I.

ABATTOIR TO KREOSOTE,

With an Introductory Essay on Invention.

LONDON:
VIRTUE & CO., CITY ROAD AND IVY LANE.
1866.

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INTRODUCTION.

◆

ON INVENTION, AS ILLUSTRATED—I. BY THE HISTORY OF PRINTING; II. BY THE IDENTITY OF THE INVENTOR; III. BY THE TIME OF THE INVENTION; IV. BY THE EFFECT OF THE INVENTION.

I was travelling some years ago in Germany, and fell in with a Lutheran minister who had been to a clerical conference at Berlin, and was returning to his parish in company with his wife and infant child. At one of the stations where we stopped, a lady, apparently the sister of his wife, got into the carriage, and eagerly inquired about the child. Almost her first question was as to its name. The answer was, "His name is John." The lady took the child, folded it tenderly to her bosom, and said, "Dear John! thou hast a most loving name." When I had an opportunity of speaking I ventured to express a hope that as the son of a Christian minister many might rejoice at his birth.

This name *John* is a favourite one in Germany, and appears under various forms, such as *Johannes, Johann, Hans, Hanschen,* or "little John," *Jean,* which is the French version, *Jan,* the Dutch, and many others; and there is also the feminine form in *Joan, Joanna, Janet,* &c. In the Hebrew it signifies "the Lord's grace," or simply "gracious," or, "in great favour," or "esteem." It is a favourite name in Germany, partly because the Germans are proud of their countryman, John Gutenberg, whom they claim as the inventor of printing with movable types, as far back as the year 1440.

On New Year's Day, 1540, the honest old printer, John Luft, of Wittenberg, recalling to mind that he had just entered on the centenary year of an invention which had conferred so many blessings on mankind, thought that something ought to be done on the part of himself and his brother printers of the town to mark their sense of so great a gift. Accordingly he made a proposal to them, and it was well received, and after much deliberation they agreed to set apart the 24th of June for the celebration: and that day was chosen not only that the sun and the flowers might be of the party, but also because it was the feast of St. John the Baptist, and in the Gospel for the day the dumb Zacharias wrote "His name is JOHN." (Luke i. 63.) They hoped that as in the case of John "many shall rejoice at his birth," so with Gutenberg's invention many had rejoiced, and would continue to rejoice at its birth.

A century later, namely, in 1640, notwithstanding the war, which from its duration bears in history the ominous title of the "thirty years' war," St. John's Day was celebrated, not in Wittenberg only, but throughout Germany. There were special services in the churches; literature and art were exerted in praising and complimenting the inventor and the invention, and all the resources of the type-founder and of the printer were exerted to perpetuate these compositions.

In 1740 the rejoicings extended to other parts of Europe; London and Paris took part in the celebration, and there was even a greater typographical display than on the previous occasion.

In the following century honest old John Luft's institution became disturbed, as I think, on insufficient grounds. Some old documents were discovered in 1745 in the Record Tower of Strasbourg, which made it probable that the invention was first made, or at least attempted, in that town in 1437. It was therefore determined to hold the next centenary festival, not in 1840, but in 1837. Great preparations were made for the occasion; subscriptions were collected from various parts of the world to defray the expenses of a statue designed by Thorwaldsen, to be erected in the town of Mayence, on the Rhine, where Gutenberg practised his art. On this occasion the Germans were the chief jubilants, and Mayence the centre of the festival: but as the preparations could not be completed by St. John's Day, the festival was not held until August, when the 14th and the three following days were devoted to its celebration.

It may be necessary for the sake of some of our readers to explain the invention which has conferred such celebrity on the name of John Gutenberg. Printing is really as old as the sands of the sea. A bird running along the sea-shore multiplies the impressions of its feet by a process of printing. Indeed, it is by such a process alone that we get information respecting certain animals that have long ceased to exist. The geologist sometimes exhibits a slab of stone from the quarry containing the cast of the foot of some very large animal—nature's stereotype of one of her extinct productions. At the time when such a cast was formed the site of the quarry must have been the sea-shore. Suppose now that the slimy mud left by the retiring tide had been partly dried by the heat of the sun. The huge animal, walking with slow and deliberate steps along the shore, left sharp and well-defined impressions of its footsteps in the stiff and partially dried mud. Then came a violent wind, bringing with it a large quantity of dry sand, which completely covered up these footmarks and protected them from the next tide. More sand accumulated, and there was also probably an upheaval of the land; so that what was the sea or the sea-shore became dry land. The sand which was brought by the winds became compacted into a sandstone rock, and in after ages men quarry into this rock, and find visible traces of a former condition of things, of which this footmark is an indication.

In very early times men were acquainted with printing or multiplying impressions by means of engraved seals. Thus we read in 1 Kings xxi. 8, "She wrote letters in Ahab's name, and sealed them with his seal." There are many other passages in Holy Writ showing how common was this method of multiplying impressions. Indeed, among the ruins of ancient cities there is abundant evidence that at an early period men were acquainted with the art of multiplying impressions by means of stamps, &c. The ancient Romans marked their cattle, horses, &c., with a metal stamp containing letters. This stamp was dipped into fluid pitch, and so printed on the bodies of the animals; but in the case of runaway slaves the stamp was made hot and printed on the captive's cheek or forehead. This we call a *brand*, because the characters were *burnt* in; an expression now happily only figurative. Bricks and tiles were also stamped while the clay was still soft; and bread was required by the Roman law to be stamped with certain letters or words indicating its composition. Examples of this practice have been found in excavating the buried city of Herculaneum; and in one case the loaves thus wonderfully preserved during 1800 years were marked in the following manner:—

SILIGO E GRANIS
ET CICERE

meaning that the finest wheat flour was mixed with the meal of peas or of lentils. The production of coins and medals by means of the punch and the die are also examples of a kind of printing. But the Chinese have, during many ages, been in the possession of printed books formed on precisely the same principle as the stamp with which the Roman baker marked his loaves, only the Chinese stamp represented the whole page of a book, instead of two or three words. That is, the Chinese artist wrote on a smooth block of wood the number of words and lines required to fill a page, writing his characters the reverse way, as we see names and letters engraved on a seal, and beginning all his lines at the right hand, so that when transferred to paper the words would have their usual appearance, and the lines be read from left to right: just as in the wax impression of a seal. Now, when the Chinese artist had thus filled his wooden block he would proceed carefully to engrave it, that is, to cut away all the wood about and within the characters, so as to leave the characters themselves slightly raised, or "in relief," as it is called. The block thus prepared was dabbed or brushed over with ink, the paper placed on its surface, and passed through a press; and thus an impression of a single page would be obtained. If the book consisted of 100 pages there must be 100 blocks written on and engraved in the same manner. Thousands of impressions might be taken from every block, and by gathering together the different pages in proper order, and in pairs, and sticking the blank sides of each pair together, thousands of copies of this individual book might be produced.

Nay, more, should all these copies be disposed of, there are the original blocks ready for use to produce another edition exactly like the first, and so on so long as there is any demand for this particular book. But should there be no such demand, the blocks are of no further use, but remain as a costly dead stock in the hands of the printer. And yet this is printing in the exact sense of the word. The wood engravings which illustrate our books and pictorial newspapers at the present day are produced in this way; and there was a time, even in Europe, when "block books," as they were called, were largely distributed. They were coarse and inferior in execution as compared with the Chinese block books, and consisted mostly of rude figures of saints, with scriptural mottoes surrounding or mixed up with the drawing, as in the case of the well-known St. Christopher, which bears date 1423. A number of these pictures, with their mottoes, being drawn on wood, engraved, and printed, the different impressions were arranged in pairs, and pasted back to back and stitched, forming a block book. Such books were circulated in the Low Countries early in the 15th century, and perhaps earlier still.

Now the great objection to this mode of printing must strike every one. The block that represents a page can print that page only, and nothing else. Suppose it were required by this method to print the Bible. The Latin version, which occupied Gutenberg three years in printing with movable type, contains 3,566,120 letters. There are 1,280 pages, and about 2,600 letters on a page. Supposing it took an artist a week to cut 1,000 letters, he would be occupied 70 years, or 70 artists one year, in engraving the blocks required for a complete impression of the Bible. The thing is evidently impossible. Now Gutenberg's idea was this: instead of engraving the letters of a page in one solid block, to engrave a single letter at a time, and having collected a moderate number of such letters, to arrange or compose them into a page, and having worked or printed off as many impressions of that page as were likely to be wanted, to unlock the page, sort out all the separate letters, and use those very same letters over again in composing or setting up the next page. In this way we get rid of a vast mass of useless engraving and wood cutting. A moderate supply of letters allows a page, or as many pages as there are on one side of a sheet, to be set up and worked off; and then the same letters, or *type*, as they are called, can be used for subsequent pages or sheets, until the work is complete. Should the work not sell, the evil is not of that magnitude as it was when all the pages were engraved on blocks, for now the same type can be used for other books until it is worn out; and even then it is not useless, for it may be returned to the melting-pot of the type-founder, to be used for casting new type. On the other hand, should there be a large demand for the book, the printer would not object to meet that demand by setting up the type and working off the sheets a second time.

Such was Gutenberg's invention; and simple as it may now appear to us, it was a great invention. It required years for its realisation, and left the man, to whom a statue has been erected, poor and broken-hearted.

John Gensfleisch von Gutenberg was born of a patrician family, according to the German writers, at Mayence, between the years 1393 and 1400.* It appears, however, from one of the town books of Mayence for June, 1430, that Gutenberg's mother, Else, then a widow, agreed with the corporation of the town to commute a pension of a certain amount into one of a less amount to be paid to her son John during his life. The assumption of this authority on the part of the widowed mother seems to show that Gutenberg was at that time under age. Four years afterwards, however, he must have attained his majority, for we hear of him in Strasbourg taking proceedings against the town clerk of Mayence for the recovery of money due to him on the part of the town. It is natural to suppose that Gutenberg having so many near relations living in Mayence, and possessing property there, should himself have been born there. But if in 1430 he was still under age, and in 1434 had attained his majority, he must have been born somewhere about the year 1412–13; but about this period, viz., in 1411, one of those frequent and often bloody disputes between the nobles and burghers of large towns took place at Mayence, and the result was that 110 of the nobles, including the Gensfleisch family, were banished. John's parents, it is thought, retired to Kutenberg, in Bohemia, where John may have been born, about the year 1412.† At this period Bohemia was celebrated for her artistic and other manufactures. She possessed the secrets or excelled other nations in the art of cutting and polishing stones, in ornamental glass and magnificent windows of stained glass. Her wood carvings and enamelled portraits were much admired; and she excelled in the art of illuminating manuscripts in gold and liquid colours of brilliant tints. It is reasonably supposed that young Gutenberg witnessed all these things, and acquired a taste for mechanical pursuits during the years devoted to his education. Another circumstance that makes it likely Gutenberg was educated in Bohemia is that when settled in Strasbourg in 1437, he was cited before the ecclesiastical court for breach of promise of marriage by a lady named Enell, who is described *Zur ysern Thür*, "of the Iron Gate." No house in Strasbourg of that name is, or has been known, but such a name has been from time immemorial applied to a house at Prague, in the Altstadt, No. 436. There is still further evidence in favour of this theory. Gutenberg's name occurs on the books of the University of Prague in 1445 as Bachelor of Arts. In the archives of this university nearly all the names are derived from places of birth; there are 86 Bachelors, or Masters of Arts, who take their name from the Bohemian town of Kutenberg. Thus Gutenberg is entered *Iohannes de Montibus Kutnis.* Another is entered *de Montibus Gutnis.* Indeed, the same person is sometimes called *de Kutnis*, and at other times *de Gutnis:* and hence *Kutenberg* and *Gutenberg* may be considered as synonymous. The German writers are not able to account for Gutenberg in 1445, but this entry in the *Liber Decanorum* may remove the difficulty.

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* Wetter's *Kritische Geschichte der Erfindung der Buchdruckerkunst.* Mainz 1836, pp. [illegible], and in other [illegible]. This work contains an exhaustive discussion of the subject from the German point of view.

† This theory is maintained by several Bohemian writers, especially and recently by [illegible] *[illegible]*, Third [illegible] pp. [illegible] [illegible] in 1867. See also Tomek, *Geschichte der Universität Prague* 1849, and the *Liber Decanorum Facultatis Philosophicae Universitatis Pragensis*. The original of this precious MS. is kept in the archives of the university; but it was printed at Prague in 1830-32, in two volumes, and contains nearly [illegible] names.

We learn from the legal records already referred to as having been discovered during the last century at Strasbourg, that about the year 1436-7, Gutenberg was actually engaged in mechanical pursuits in company with several persons who paid him various sums of money for instruction in certain profitable pursuits. Thus he taught Andrew Dritzehn the art of cutting and polishing stones, and he also agreed with one Hans Riffe to prepare some small wares to be sold at the fair of Aix-la-Chapelle, to be held in 1439, on the occasion of the septennial pilgrimage to that city, when the numerous relics were exhibited to the faithful. These men worked together in secret, and when questioned as to the nature of their pursuits they said they were manufacturing looking-glasses for the fair. All the writers I have met with adopt this view; but I cannot help thinking there was a double or latent meaning in the explanation. Block books had been circulated for some years, and many of them were known under the title of *specula*, or mirrors. Thus we have the *Speculum Humanæ Vitæ*, or Mirror of Human Life, the *Speculum Salvationis*, or *de Confessione*, or *Speculum aureum animæ Peccatricis*, and many others. Now there is evidence to show that in 1436, Hans Dunne, a goldsmith of Strasbourg, had been employed by Gutenberg in matters connected with printing; and my notion is that Gutenberg was seeking to multiply block books by an expeditious and cheap method of printing with movable types instead of having to engrave a separate block for every separate page. There is abundant evidence that he used every precaution to keep his experiments as secret as possible; and in order to divert inquiry, he actually made some small looking-glasses as specimens of what he intended to take or to send to the fair. I do not attach much importance to the theory that finds a motive for Gutenberg's secresy in his nobility, which would be degraded by practising a mechanical art; since noblemen were glass-workers, silk-growers, and afterwards printers, without any loss of caste, and Gutenberg though noble was poor, and sought to increase his fortune by the practice of an art which he intended to work for his own pecuniary benefit, a motive which publicity would have destroyed. Dritzehn seems to have found the art of polishing stones, which he learnt from Gutenberg, to be profitable; and hearing that Gutenberg and Riffe were shut up together for the purpose of carrying out some other scheme, begged to be allowed to make one of the party. This was agreed to on the payment of a sum of money. Moreover, one Heilmann, hearing of the concern, begged Gutenberg to take his brother Antony into the partnership. Gutenberg consents, but cautions him to secresy, on the ground that his relatives may think he is practising sorcery. An agreement or deed of partnership is now drawn up, by which Andrew Dritzehn and Andrew Heilmann were to have one share of the profits between them, Riffe one share, and Gutenberg the remaining two shares. Dritzehn and Heilmann also agreed each to pay Gutenberg 80 florins for his instructions. There is evidence that Dritzehn borrowed money of Heilmann in order to pay his premium, which was done on the 22nd of March, 1438. It does not, however, appear that Gutenberg had confided to his partners his grand idea of printing with movable types; he may have taught them how to make actual looking-glasses, while he deemed the secret of the figurative ones too valuable to be yet disclosed. At any rate the partners notice in April that Gutenberg is working at some art which he conceals from them. They express their displeasure, and urge him to tell them what he is about. Gutenberg, fully alive to his own interests, requires a fresh agreement, and makes harder terms. They must go on adding to the 80 florins until it becomes 500; and each must pay down 170 florins. One witness said, however, that it was Gutenberg who made the first proposal to form a partnership on this broader basis of capital. If they consented he would tell them all he knew, and there should be no secrets among them. This was agreed to, and five years was named for the period of partnership. Should, however, any one of the partners die, the whole of the tools and stock-in-trade to belong to the survivors; but in order that the representatives of the deceased partner should keep quiet, they were to be paid 100 florins, on condition of not prosecuting any claim to enter the partnership, or making any disturbance. Under the new agreement Heilmann and Dritzehn were to pay 125 florins each. On the 15th of July they paid portions only of their shares, and Gutenberg retaliated the breach of faith by not commencing his instructions. In the autumn of that year they asked when he was going to begin. He asked them when they were going to pay. They were often at Gutenberg's house, eating and drinking and talking over their concerns; and Gutenberg afterwards complained of the quantity of wine they drank. About harvest Dritzehn pressed one of his tenants for money, on the ground that he had work in hand which required more capital. When asked about his work, he said it was making looking-glasses. The tenant, Hans Nigen, thrashed his corn, sold it, and paid Dritzehn. The partners soon after went to several places and bought lead and other things, for which Dritzehn became responsible. Gutenberg, however, denied the latter part of the statement; but there is no doubt that the partnership got into debt, for they gave a bond for 101 florins, which Dritzehn refused to seal, and it was afterwards (that is, in March, 1439) paid by Gutenberg. There is the evidence, too, of Conrad Sahspach, that he made a press, and knew for what purpose it was to be used, and he thought so well of the invention, that he lent money to Dritzehn, who applied it to the work in hand. Frau des Reinbold also lent money to Dritzehn, and with womanly prudence advanced 5 florins on a ring that was worth 30. The partners now seemed to be working in earnest; and in order to keep Gutenberg in good humour, Dritzehn sent him in October half an ohm of wine (about 15 gallons), and afterwards, in conjunction with Heilmann, 8 ohms, as their share, as they said, of the eating and drinking; but Gutenberg afterwards declared that these presents did not repay him. Dritzehn was now working day and night, and his aunt, Ennel, assisted him. He told her he had already paid 400 or 500 florins, and that the invention would cost him still more; but before a year was over he and his partners would get back all their capital and be prosperous ever after. About the same time, however, he told another witness that the work had cost him only 300 florins, while he named 500 to his creditor, Reinbold; he is confident, however, that when the invention is complete he will be able to discharge all his debts, and be well repaid for his trouble. Just before Christmas we find Gutenberg sending his man to Dritzehn's house, and also to Heilmann, to fetch away all the *formen*, i.e., *forms*, the very word used by printers at the present day. Dritzehn is at this time ill in bed, and the priest, Erkart, who visited him on the 27th, said he complained of having 200 or 300 florins in Gutenberg's concern, and not having yet received any profits. During the Christmas holidays Dritzehn died, still in debt to Gutenberg, who at once sent for the presses, or gave directions to take them to pieces, lest any one should see them; for he remarked that people had become curious about their affairs. He also invited Claus Dritzehn to an interview. The man who went with this message said that no one was to see the presses, and that he had instructions to take out two large screws, when the press would fall to pieces, and the separate parts were then to be piled up, so that no one should be able to tell, on mere inspection, what they were intended for. It appears, however, that Heilmann had already taken care of the presses.

Dritzehn's relations found at his lodgings the partnership agreement, and there appears to have been some negotiation between the parties. In March, 1439, Gutenberg, as already noticed, discharged the partnership bond of 101 florins, and soon after this date George and Claus Dritzehn commenced an action against Gutenberg for the recovery of their deceased relative's capital, or for admission into the partnership. The cause came on for trial on the 12th of December, when Gutenberg and the other partners were examined on oath as to their dealings with Dritzehn, and the judgment of the Court was that Gutenberg should pay the sum agreed on in the event of the death of any one of the partners, but that he be entitled to deduct from that sum the money due to him, from Dritzehn, at the time of his death. The plaintiffs were accordingly entitled to the sum of 15 florins, which was paid.

All this information I have condensed from the somewhat wordy records of the Court, discovered, as already remarked, in 1745. They prove conclusively that Gutenberg was conducting experiments in the art of printing with movable types, probably of wood. The surviving partners may have continued with Gutenberg during the stipulated five years—namely, from the summer of 1438 to that of 1443. At any rate, Gutenberg was at Strasbourg in 1444, as is shown by an entry in one of the town books, recording the payment of a tax; and there is also evidence that during the four years after Dritzehn's death, Gutenberg contracted several debts, and also disposed of his little property. Between 1444 and October, 1448, the German writers cannot account for him; but, as already shown, from the entries in the *Liber Decanorum*, Gutenberg may have returned to Prague, probably to improve his scholarship, and also his acquaintance with the mechanical arts. We hear of him again in October, 1448, still as a borrower, and still probably possessed with the leading idea of his life. Soon after this he met with John Fust, a rich burgher and goldsmith of Mayence, to whom he communicated his still imperfect invention. Fust saw how much the idea promised, and agreed to enter into partnership with Gutenberg for carrying it out. Fust was a man of business; Gutenberg only an inventor. Fust was a man of capital; Gutenberg afflicted with poverty. No wonder, then, that the rich man bound the poor one hand and foot, so as to make use of him as long as he served his purpose, and then, when no longer wanted, he would fling him aside like a squeezed orange. Articles were drawn up by which Fust agreed to *lend* Gutenberg 800 florins in gold, at 6 per cent. interest, which money was to be expended in carrying out the invention, the invention to be security for the loan; to allow 300 florins yearly for expenses, such as wages, rent, parchment, paper, ink, &c., and in case of disagreement, Gutenberg was to pay back the 800 florins; but everything which had been purchased with the annual allowance was to be partnership property. The agreement is dated 22nd of August, 1450.

It seems probable that Gutenberg's attempts at printing in movable type had not hitherto been attended with much success, or he would have made better terms with Fust. It is supposed that during his residence at Strasbourg he printed some block books, and also succeeded, after many attempts, in making a good black ink adapted for printing. He may also have been partially successful in some of his attempts with movable types. These were made of pear and box wood, and were bored so as to be threaded on a wire; they were set up or composed by thus threading them, and the method was so far convenient that whole lines could be easily lifted about. In 1450, or early in 1451—that is, after having joined Fust—a *Donatus*, or Latin grammar, was printed with such type. There was no oil in the composition of the ink, so that it can be washed out with water. But Gutenberg's great object—with which, doubtless, Fust sympathised—was to print a complete copy of the Bible. A manuscript copy, on vellum, was at that time worth an estate, and the idea seems to have been to imitate in type the written character of the period, and pass the printed copies off as manuscript. We are not informed as to how the many difficulties of this undertaking were met and overcome. That they were numerous, and called for much patience and self-denial during the three years that were occupied on the task, cannot be doubted. Some writers have supposed, from the defective appearance of the letters, that Gutenberg's Bible was printed with wooden movable types. There can be no doubt, I think, of the fact, that Gutenberg used metal types, and that he contrived matrices for casting them. It is not known what material he used for his matrices; they were probably of lead, or of lead and tin. A Paris type-founder has proved by experiment that letters can be cast in such a matrix; that from fifty to sixty letters can be produced from one matrix, but that the finer lines become gradually lost. This, it is thought, will account for the fact that letters of the same name and in the same page, in one of Gutenberg's books, show considerable differences in sharpness and definition. Fust's trade as a goldsmith must have made him acquainted with the various methods of working in metal; and it seems that attempts were made to cut or shape the type separately by hand. But this is evidently so costly a process that it must soon have been abandoned. Many experiments were doubtless tried, and money was spent. Fust's son-in-law afterwards stated that they had expended 4,000 florins before they had printed the third quaternion of the Bible, each quaternion making four sheets. The printing of the Bible was commenced in 1452, but still there must have been difficulties requiring more experiments, more capital; for on the 6th of December of that year, Fust advanced another 800 florins, retaining, however, 140 for the arrears of interest on the former sum. Gutenberg's difficulty, no doubt, was to provide type for the great work; but surely the cost of overcoming it ought to have been equally shared between the partners. Fust probably said, "The invention is not complete; show how you can make your type in a good and workman-like manner, and at moderate cost, and then I will join you on equal terms." This type-founding was Gutenberg's weak point, and ought to have been his strongest, in order to carry out his invention. Experienced type-founders and printers have carefully examined existing copies of Gutenberg's 42-line Bible, as it is called, and agree as to the imperfection of the casting of the type. The letters, they say, though similar in size and form, are deficient in outline; the edges, points, and angles, being more or less blunt. All this shows imperfect casting; a remark which equally applies to the other books printed by Gutenberg during his connection with Fust. A brief notice of these, the first books ever printed in movable type, will be of interest. They consist of—

1. *Donatuses* printed partly with solid blocks of wood, partly with wooden movable type, and partly with movable metal type. They are all without date, and have no printer's name or place.

2. The *Letter of Indulgence* of Pope Nicholas V. to those who assisted the King of Cyprus in his war with the Turks. It is printed on parchment, and there are six copies of it in existence. The oldest contains 31 lines, and is dated 15th of November, 1454. The characters MCCCCLIIII are printed, the rest of the date being written by hand.

3. The *Warning against the Turks*, consisting of 9 printed quarto pages, of from 20 to 21 lines. There is one copy in the Royal Library, Munich; one in the University Library of Leipsic, and one in Earl Spencer's library. The book begins with a prayer to the Almighty, then follows the warning in 12 parts, each headed with the name of a month. The first contains exhortations to the Pope, the second to the Emperor, the third to kings, the fourth to archbishops, the fifth to princes, the sixth, &c., to dukes and free towns, and the last contains an account of the dangers with which the Turks threaten Christendom, and ends with wishing for a happy new year. That the book was printed at the end of 1454 is evident, for the Pope to whom it is addressed died on the 24th of March, 1455. The work is printed in what is called missal type.

4. The *Latin Bible* of 42 lines, finished in 1455, and containing 641 leaves, folio, the first volume 324, the second 317, making together 1,282 pages. Each page contains 2 columns, each column is 10 inches and 9 lines high, and 3 inches and 5 lines wide. The pages are not numbered, and there are no signatures, catch words, or initial letters. In the first 9 pages each column contains 40 lines, the next 10 pages 41, but all the rest of the work contains 42 lines in one column, and this gives the distinctive name to the Bible. The work is gathered, or made into portions of 5 sheets, and these are distinguished by written catchwords. The letters are in missal or Gothic type of two sizes, and, [illegible] the written character of the period. The first volume commences with 3 lines printed in red, "*Incipit epistola sancti Hieronymi ad Paulinum*," and the letter of St. Hieronymus to Paulinus follows. The second volume also commences with [illegible] of the same colour in the Book of Solomon. The work was printed both on parchment and on paper. The paper is white and strong, and has four different watermarks, viz., the ox's head, with the pole and cross-beam, the single ox-head, [illegible]; and the cluster of grapes. The ink is black, strong, and lustrous, and [illegible] partially [illegible] with distilled water. The initial letters are all painted, in the parchment copies, in beautiful colours and gold, and in the paper copies in red and blue. There are [illegible] copies of this Bible extant—7 on parchment, 8 on paper. Those who have [illegible] find [illegible] differences in the number of lines, and in the spelling and contraction of words, so that changes in the printing must have been constantly made, or, what is more likely, some of the pages [illegible] with variations.

Of the parchment copies, there is one in the Imperial Library at Paris, purchased in 1767, from the [illegible] monastery at Mayence. There is a copy at Berlin, one at Dresden, one in the Barberini library at Rome, and in Lord Grenville's library. A copy was sold out of the University library at Mayence, [illegible], and purchased by Mr. Perkins, the brewer, for £504. A copy would fetch probably many times that sum at the present day. There is a copy in the University of Leipzig, and the fragment of a leaf in the town library at Mayence. The copies on paper are in the Imperial library and in the Mazarin library, at Paris, also at Munich, Aschaffenburg, Frankfort, Trèves, Leipsic, and in Lord Spencer's library. The original edition probably did not exceed [illegible] copies, of which about sixteen are still known to be in existence.

While Gutenberg was thus slowly and laboriously labouring at his system, engaged with the stupendous task of printing the whole of the Bible for the first time, a keen-sighted clever assistant of Fust, named Peter Schœffer, was looking on, and gradually getting to understand the weak point in Gutenberg's proceedings. He devised a remedy, put it partly into practice and secretly communicated it to his master, Fust, who was so delighted with it, that he promised to reward his complete success with the hand of his daughter, Christina, and a share in the partnership. Schœffer's idea was this:—to cut a number of steel *punches*, according to the number of the letters of the alphabet, or of the sorts required, and having bestowed the greatest care in finishing off these punches in the most artistic manner, to harden them, and use each punch for generating a number of *matrices*, each of which would furnish any number of letters by casting. For example; suppose the hardened steel punch to represent the letter A in relief, this punch can be used to impress that letter upon the softer metal of the matrix, in which of course it will be sunk, or *in intaglio*, as it is called. From this matrix, by proper arrangement, any number of letters may be cast. Having once got the punch in hard steel, any number of matrices may be formed by its means; so that any number of type-founders may be multiplying the same letter at the same time. This was the first part of Schœffer's invention, namely, the formation of the punch. The second part referred to the material of the matrix. Instead of using a soft metal liable to degradation by use, as Gutenberg had probably done, he employed copper, a much harder and more durable metal than lead or pewter, which Gutenberg is supposed to have used, or the alloy of lead and tin, which was melted and poured into the mould for forming the type. We can fancy that he would be dissatisfied with the blunt castings produced by lead or pewter, and taking advantage of the facilities offered to men whose trade is in metal, would vary the composition of his type-metal until he had obtained satisfactory results.

Such was Schœffer's invention, the hard steel punch and the copper matrix, and they continue to be used by the type-founders at the present day. Whether Schœffer discovered the value of the metal antimony in causing the type metal to fill the mould, and so produce sharp characters, cannot now be ascertained. Antimony was known at the time, for it formed the subject of many experiments by the monk and alchemist, Basil Valentine, early in the century to which we refer. It possesses, in common with water, the remarkable property of expanding when it passes from the molten or liquid into the solid state; so that, like ice, the solid is a little lighter than the liquid, and floats upon it. Good type metal is composed of two parts of lead, one of tin, and one of antimony; sometimes a little copper is added. The antimony not only makes the metal fill the mould, but confers toughness on the alloy, and sufficient hardness to bear the wear and tear of the press, but not hard enough to cut the paper.

Schœffer's improvements are undoubtedly of first-rate importance, and were felt to be such both by master and man. Hence they were carefully concealed from Gutenberg, who was allowed to go on with his imperfect materials until he had finished printing the Bible. Some suppose that Schœffer invented his method about the time when the third quaternion had been worked off, and that the type having been so much improved, the sheets already printed were cancelled, and the work begun over again in the new type. A comparison, however, of the first work printed by Fust and Schœffer, after having separated from Gutenberg, shows conclusively that Gutenberg had no share in Schœffer's invention; for whereas Gutenberg's letters are of uncertain and feeble expression, those of Fust and Schœffer are sharp, clear, and distinct. Even after the separation, when Gutenberg had a printing-office of his own, his letters are still inferior, showing that he was not master of Schœffer's invention, or at least did not possess the whole of its secret.

The time having arrived, that is, Fust having made all the use he could of Gutenberg, a separation was determined on, and the grounds of separation were not far to seek,—namely, the non-payment of interest on money which ought to have been partnership capital. In October, or perhaps a little earlier, Fust commenced law proceedings, and the law on this occasion must have quickened its usual tardy pace, for the cause was decided on the 6th November following, in the dining-hall of the Franciscan monastery opposite Fust's house. We learn from the record of the proceedings that on this day, between eleven and twelve, John Fust, accompanied by his brother Jacob as spokesman, appeared before the notary, Helmasperger, the monks being in their cells. Jacob Fust inquired whether John Gutenberg or his attorney were present. Whereupon the priest, Chünther, of St. Christopher's, and two of Gutenberg's servants, or journeymen, came forward, and said they were sent by Gutenberg to see what was going on. Thereupon Fust required that as the day had arrived, and Gutenberg had not appeared in person, judgment should be passed. The plaintiff's declaration was now read, together with the defendant's plea, as well as the judgment or verdict. The declaration stated that he, John Fust, had agreed to lend John Gutenberg 800 florins, at 6 per cent., for the completion of a certain work, whether that work cost less or more; that he, Fust, had himself to borrow this money at interest; that he had lent Gutenberg a second sum of 800 florins; that interest had not been paid on those sums, and that Fust had had to pay it himself; that in order to raise the money he had to go about amongst Christians and Jews, and had to pay large usuries; so that altogether, including capital and interest, he had a claim against Gutenberg amounting to 2,050 florins, the payment of which he demanded without delay.

Gutenberg's answer was to the effect that, according to agreement, Fust was to lend him 800 florins for the purchase and preparation of plant, which was to be Fust's security. Fust was to pay 300 florins a year for expenses, and in the event of disagreement, Gutenberg was to pay back the 800 florins, and then the plant was to be free from encumbrance. The 800 florins referred to the plant only, and Gutenberg hoped it would not be considered that it was his duty to expend any of the 800 florins on parchment, paper, ink, compositors' wages, and presswork. It was true that 6 per cent. interest was in the agreement, but Fust had promised not to charge him with interest. It was further stated that the 800 florins had never been paid in full; that with respect to the second 800 florins, he would furnish Fust with an account how that sum had been expended; that he had no right to charge interest on this sum, still less compound interest.

The judgment of the court was that Gutenberg should account for all sums he had received and had expended for the partnership, and all payments for parchment, paper, compositors' wages, and presswork, and then that the stock in hand be sold for the mutual advantage of the partners. All money expended by Gutenberg for plant to be included in the 800 florins for which the plant was in pledge; but other money advanced by Fust, and not expended for the benefit of the partnership, to be repaid by Gutenberg, Fust to declare on oath that he did not advance these sums out of his own capital, but had to borrow the money and pay interest for it; Gutenberg in such case to repay the interest according to the agreement. This oath having been taken, the proceedings terminated.

The great unfairness of the agreement which Fust insisted on carrying out to the letter lies in the fact that Fust should lend money to Gutenberg for plant, and then put himself in the condition of a mortgagee on such plant, while without it they could not print the books in which Fust took an equal share, while both partners shared equally in the other expenses, such as parchment, paper, compositors', and press work, &c. Still it may be said that the whole impression of the Bible, as well as of the smaller works, was partnership property, and the sale of the first printed Bible, one would suppose, would have been abundantly sufficient to have enabled Gutenberg to discharge all his obligations to Fust, and to have retired with a handsome sum in hand. Fust's crafty agreement, however, prevented so reasonable a course. Not a single copy of the Bible was allowed to be sold until Gutenberg had satisfied the inexorable claim. By the non-payment of the first 800 florins and interest, Fust became possessed of the plant, type, presses, &c.; and for a similar default respecting the second 800 florins and interest, the entire stock-in-trade was seized by Fust. Fust stated that the second 800 florins had been spent by Gutenberg on his own affairs, and the court apparently recognised this statement by ordering that all payments by Gutenberg for plant should be included in the first 800 florins. The making out of accounts was probably a matter of difficulty and dissatisfaction. Gutenberg, a noble by birth, and attached to mechanical pursuits, was not likely to have the virtues of a book-keeper, and while Fust required the expenditure of every penny of his money to be accounted for, Gutenberg would rather deal with the whole in a lump, without going into minute details.

Thus, after years of incessant toil in carrying out his invention, and the production of a complete edition of the Bible, printed for the first time, Gutenberg saw himself deprived of the fruit of his labour, and had to begin life anew. So little is the man honoured by the Great Disposer of events, that in carrying out a process which was to spread His Word over the face of the earth, the inventor falls to the ground, and the grasping, selfish capitalist prospers. Even after Fust's death the younger Fusts pursue the relatives of the childless Gutenberg with law proceedings, on account of some still unsatisfied claim. They even seek to deprive Gutenberg of his share in the honour of the invention by giving the sole credit to Fust and Schœffer.

Fust's motive in throwing Gutenberg overboard was doubtless a mixed one. In birth and education Gutenberg was superior to his partner; he regarded the invention as his own, and Fust as the money lender. The burghers and the nobles were often at feud, and Gutenberg may have mixed a little arrogance in his dealings with the goldsmith; and the connection was probably embittered by failures in experiments, and disputes about money expenditure. When, however, Fust saw the means of vastly improving the art by Schœffer's invention, he determined to get rid of Gutenberg in such a way as to deprive him of his share in the original invention, and of any participation in Schœffer's improvements. Probably in the same spirit he secured Schœffer by making him his son-in-law and partner. Keep Schœffer's improvements secret, and then there need be only one printing-house in the world, and that the house of Fust and Schœffer. Keep Schœffer's improvements secret, and Gutenberg's art, as practised by himself, would be useless on account of his very inferior type.

We learn from the Fust papers that Gutenberg was very angry at the result of the law procedings, and quitted Mayence in disgust. This was at the end of 1455. We hear nothing of him for about two years. With the natural shrinking of an unsuccessful man, he probably kept out of sight, mistrusting even those who were disposed to befriend him. Some suppose that he went to Strasbourg to look for friends and patronage; it is even said that he set up a printing press in that city and failed. He returned to Mayence some time in 1456 or 1457, and with the assistance of Dr. Humery, set up a printing press, and commenced printing the Catholicon, or Latin Dictionary, of John de Janua. This took him three years. It contains 746 folio pages of close type, and forms a good specimen of the art, although bearing evidence of inferiority to Schœffer's type in the way of clearness and sharpness. The Latin letters of the time are used. There is a Latin inscription or colophon at the end of the work, which is remarkable for its simple piety. The following is a free translation:—"Under the protection of the Most High, at whose will the tongues of children become eloquent, and who often reveals to the lowly what He conceals from the wise, this excellent book, the Catholicon, was prepared in the year MCCCCLX. of the humanity of our Lord, in the good old German town of Mayence, which by the goodness of God is preferred to the other nations of the earth for so high an illumination and free gift of grace as that by which this book is produced, not by means of a reed, stile, or pen, but through the remarkable discovery and working together of punches and matrices." Then follow four Latin verses of praise and honour to the Holy Trinity and the Virgin. Gutenberg does not attach his name to the above colophon, some say on account of his noble extraction; but noblemen at the time did not object to exercise arts which produced profit, and printing soon became to be thought so noble an art, that printers were allowed the gentleman's privilege of wearing a sword. Others suppose that Gutenberg withheld his name on account of the inferiority of his work to that of Schœffer, Gutenberg's ill-defined type, and badly shaped initial letters, contrasting painfully with Schœffer's well-cut type and splendidly coloured wood-cut letters.

Meanwhile Fust and Schœffer brought out several works, including a Latin Bible, in beautiful Gothic Latin type. This work appeared on the 25th of June, 1462, soon after which an event occurred which at first sight would seem to be most disastrous to the prospects of the young art, but really was most useful to its welfare. On the 28th October, 1462, the town was besieged by Adolphe von Nassau, who had been appointed by the Pope Archbishop of Mayence, in place of the deposed Archbishop Diether von Isenberg. The city fell after a stout resistance, and was sacked and partly burnt. Fust's house was destroyed by fire, the printers were dispersed, and, travelling to different cities, set up printing presses on their own account. Fust's house was begun to be rebuilt in the spring of 1463, and it was not ready for occupation by the partners until late in 1465. In the interval the art was gaining strength, and exciting the admiration of mankind in other parts. Gutenberg's house seems also to have suffered so much in the siege that he made no further attempts at printing. He entered into the service of the new archbishop, while Dr. Humery took possession of the printing-house and sold the plant to a citizen of the town. Gutenberg died somewhere about February, 1468. He was poor and childless, and his death excited no remark in the town he had so much benefited. One of his relatives, after an interval, erected a stone to his memory, from which it appears that his bones rested in peace in the church of St. Francis, at Mayence. His arms were placed over his tomb; but both tomb and arms were destroyed, it is supposed, about the time when the town was taken by the Swedes, on the 13th of December, 1631, and the Jesuit College turned into barracks. The tomb was probably either destroyed by the troops or by the equally destructive processes of the restorer during the subsequent repairs. Diligent search was made for Gutenberg's tomb in 1728, but no trace of it was to be found.

The house of Fust and Schœffer continued to flourish, and to issue works, which even in the present day are regarded as masterpieces of typography. But it must be remembered that the illuminated manuscript books of the period had attained their highest excellence, and served as worthy models for the first printers. The highly illuminated MSS. on vellum to be seen in the Library of the British Museum will enable the reader to judge of the beauty and costliness of books just before printing was introduced. Within two years after Gutenberg had been so shamefully ousted, namely, on the 14th August, 1457, Fust and Schœffer brought out a splendid Psalter of 208 pages folio, the first production of the printing press that contains the date, the printer's name, and the place. The colophon is in Latin, and may be translated as follows: "The present Psalter, adorned with beautiful capitals and a distinctive Rubric, has been produced to the glory of God, by means of types without any use of the pen, by the industry of John Fust, citizen of Mayence, and Peter Schœffer, of Gernsheim, A.D., 1457, on the eve of the Assumption." In the atlas of plates attached to Witter's treatise already referred to are a number of lithographic *fac-similes* selected from this magnificent work, including some of the illuminated capital letters (of which there are 288 in the original). There are also *fac-similes* of a portion of Gutenberg's Bible, so that the reader can compare the two, and notice how very superior is the work of Fust and Schœffer. The Psalter is printed in missal type of two sizes, and resembles the Church choral books of the period. The ink is of a beautiful black, made with oil, and insoluble in water, so that in this respect also a great advance had been made. The cost of bringing out this work must have been enormous, and there is a tradition that the printers were assisted in the undertaking by the Knights of St. Alban's, and also by the Benedictine monastery. A copy was purchased in 1817 for the Royal Library at Paris at the price of £480. At the present day a copy would probably fetch many times that sum. In August, 1459, a second edition of this work appeared, and some printer's errors in the first edition (such as *Spalmorum* for *Psalmorum*) are corrected. In October of the same year also appeared the *Rationale Durandi*, a treatise on the liturgical offices of the Church, of [illegible] folio pages; on the 25th of June, 1460, the *Constitutiones Clementis V.*, of 102 folio pages; and on the 14th of August, 1462, the celebrated Latin Bible, *Biblia Sacra Latina Vulgatæ Editionis, ex translatione et cum præfatione S. Hieronymi*. It is in two volumes folio, of 484 and 478 pages respectively; it is printed with entirely new type, in two columns of 48 lines to the page. It is the first Bible with a printed date, and is known as the "Mayence Bible."

Soon after the completion of this great undertaking Fust seems to have travelled for the purpose of selling his books. In 1466, between March and July, he was in Paris. There is an anecdote of his having sold a copy of the Bible to the King of France for 700 crowns, and another copy to the Archbishop of Paris for 500 crowns; that the two purchasers on comparing their respective copies were struck with their exact resemblance, which they could only account for by the agency of sorcery, and Fust was in some danger of being burnt, had he not disclosed the secret of his art. The story is not likely to be true (although it is said to have originated the legend of the Devil and Dr. Faustus), because the Court of France must have been acquainted long before with the results of an art which had excited so much astonishment in the world. Fust is said to have died of the plague during his visit; for six months later Schœffer brought out a book of Thomas Aquinas, with his own name standing alone as printer; and some years later he seems to have visited Paris, where he founded a mass for himself, Conrad Henlif, and John Fust, citizens of Mayence, book-printers, together with their wives, sons, parents, friends, and benefactors.

In the works brought out by Schœffer and his immediate successors, the colophons contain information as to the invention of printing which is sometimes a little contradictory. Thus in the colophon of the "Institutes of Justinian," dated May 24, 1468, Gutenberg and Fust are named as the inventors of printing, and Schœffer as the scholar who excelled his masters. Schœffer's last book was the fourth edition of his superb Psalter, which, according to the colophon, was finished on the 21st December, 1502. He probably died within a few months of this date, for the next book that issued from his house bears the name of John Schœffer, son of Peter, as the printer. In one of his colophons printing is said to have been invented by the scientific mind of Gutenberg, and improved by Fust and Schœffer. But in 1515 he declares his grandfather Fust to have been the first inventor of printing.

Peter Schœffer had agents in Paris and other great towns for the sale of his books. In 1474 his Paris agent died without having been naturalised, when the King's commissioners took possession of the stock and sold it; whereupon Schœffer and his partner Henlif applied for redress to the Emperor Frederick III., and also to the Archbishop of Mayence, and their applications seem to have been so well attended to, that by an ordinance of the 21st of April, 1475, the king, Louis XI., ordered compensation to the amount of 2,425 dollars of gold. The ordinance is still extant.

The first town that followed the example of Mayence in setting up a printing-press was Bamberg, and this was as early as 1458. Indeed, it has been contended that the 36-line Bible, printed by Pfister at Bamberg, was brought out between 1455 and 1458. But this has never been quite established, and Pfister appears to have been one of Gutenberg's journeymen. Frankfort had a press in 1459; Strasburg, probably before 1462; Cologne in 1462, under the celebrated Ulrich Zell; Rome in 1465; Vienna probably earlier; Paris, 1469; Belgium and Holland 1473; Caxton had his press at Westminster in 1474; and there was a press at Oxford in 1478.

Such, then, is the history, so far as it has been ascertained, of the first three printers with movable type. There are some reflections and details which seem to connect themselves naturally with this great invention but which we can only glance at in this place. They relate to certain peculiarities which seem to belong to every great invention, and by a great invention I mean one that has had a marked influence on the intellectual and social condition of men, making them, in many respects, different after the invention to what they were before. It has been the business of a considerable portion of my life to inquire into other men's inventions, and if I had to write a history of invention I should arrange it under three great heads, namely, *first*, the inventor; *second*, the time of the invention; and, *third*, the effect of the invention; or more briefly, the man—the time—the effect.

And first, as to the inventor. He may be a good man; he may be a bad man; he may be, and indeed generally is, a man keenly alive to his own interest, for which he is content to sacrifice time and health, and is often indifferent to fame. Such is in general the man to whom we erect statues, and fall into a species of idolatry which bears the milder name of "hero-worship." That this practice is reproved in the order of Providence is, I think, manifest by the fact that the most important of the useful arts, such as agriculture, metallurgy, tanning, baking, &c., have no history. They involve difficult and recondite processes, and indicate, in the absence of science, the teaching of a higher power, as indeed we are expressly informed in several passages of Holy Writ. "This also cometh from the Lord of Hosts."* That we should give God the glory is also manifest from the fact that in comparatively modern inventions of importance, the identity of the inventor is seldom made out. In many cases we do not even know his name. We know very little, I may say nothing, about the inventor of gunpowder, and absolutely nothing as to the inventor of the mariner's compass. But it may be said the authors of these great inventions are lost in the dust of ages, because there have been the ages to accumulate the dust. Well, then, take such recent inventions as cotton machinery, railways, the locomotive, and the electric telegraph. Arkwright certainly never made out his claim to the invention of the first, and it is not possible to point to one inventor of the second and third; and as to the fourth, it is claimed by the Danes, the French, the Germans, the Americans;—we believe the inventor to be an Englishman, distinguished for many striking discoveries in Physical Science. But to go back to printing; surely there is no doubt about Gutenberg's claim to the invention of printing with movable types. No doubt! Why seventeen cities claim the invention, and one of those cities, namely, Haarlem, in Holland, has actually erected a statue to one Laurence Koster, the so-called inventor of printing with movable types. And the Dutch even go further than this; they assert that Gutenberg, disguised as a workman, entered Koster's service under the name of John, and actually stole the invention from his master; not the idea only, but the actual wooden movable types, with which Koster is said to have printed a *Donatus*, a Latin Grammar, and other small works, some years before any one had heard of Gutenberg's invention; and that he was so dispirited at the loss that he abandoned printing. In cases of this kind all one can do is to weigh the evidence as judicially as possible, and apportion to each man his claim. I do not think the evidence in favour of Haarlem sufficient to maintain the serious charge against Gutenberg; but there are acute-minded men who do. I do not mean Dutch writers, who, we may suppose, have national prejudices, but acute Frenchmen, such as M. Laborde.† He does not exactly go with the charge of theft, but thinks it made out that in 1423 Laurence Koster printed a Donatus in wooden movable types, and that the book, being hawked about the neighbouring countries, attracted Gutenberg's attention, and that he set to work to imitate it about the year 1437.

In the second place, as to the time. When the Apostle writes of "the times or the seasons which the Father hath put in His own power," he includes, I think, in those words a broad principle of action in God's providence. My reading has taught me, respecting these great inventions, that if the time in the order of Providence has not yet arrived, the invention is not made, even though all the materials for it exist, and the idea seems to be floating in men's minds, and they talk and reason together about it. As in that memorable walk to Emmaus, the disciples were communing and reasoning together about their Lord and Master, when He drew near and went with them and questioned them, "but their eyes were holden that they should not know him." It is so with the materials of a great invention. These are apparently all at hand, but men's eyes are holden so that they cannot seize and appropriate the idea, and the reason is that the time has not yet arrived. They talk about the thing and declare it impossible; the thing is done, and then they say it is so simple a child might have found it out.‡

The ancient Romans, we have seen, knew how to multiply impressions by stamping, which is a kind of printing. I have now to show that the idea of movable types was among them, but their eyes were holden; they could not see what important results would arise from pushing this idea to its legitimate conclusion. There was doubtless a purpose in this. Had the ancient Romans been possessed of this great invention their books would have been multiplied indefinitely, and readers, instead of being confined to the wealthy and the learned, would also have been multiplied indefinitely, and the world become so saturated with Paganism, that, humanly speaking, the spread of Christianity would have been impossible. That the Romans were accustomed to the idea of separate letters in some solid material (type in fact) is evident from a passage in Cicero, who in common with all good writers draws his figures of speech from familiar objects. In his treatise respecting the nature of the gods, he is arguing against the atheistic idea that this wonderful and beautiful world should have been formed by chance, or by a fortuitous concourse of atoms, and remarks that he would as soon believe that if a countless number of the twenty-one letters of the alphabet, made of gold or other material, were thrown upon the ground, they would arrange themselves so as to form the text of the book known as the "Annals of Ennius." "I doubt," he naively adds, "whether fortune (chance) could make a single verse of them." (Lib. ii., c. 20.) Now here we have what a modern printer would call a "fount of type," with a suggestion for arranging the letters in a required order; yet no one seems to have thought of pushing the idea further, so as to multiply books rapidly, and supersede the existing method of multiplying manuscripts slowly. Again, Quintilian, who lived about 146 years after Cicero, expresses his opinion that children may be taught to read more easily by giving them the separate letters cut out in ivory to play with. Here again we have the idea of movable type. There is also a letter early in the fifth century in which St. Hieronymus replies to a Roman lady named Lœta, who asked him as to the best method of teaching her daughter Paula to read. He recommends that the several letters be cut out in box or ivory, and used as playthings. The names may be taught in play by shifting them about, so that what was in the middle may now be at the top, now at the bottom. Here again we have the idea of composing with movable type.

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* Isaiah xxviii. 29 (see also ver. 26); Exodus xxxi. 3; xxxvi. 1; 1 Kings vii. 14.

† *Débuts de l'Imprimerie à Strasbourg.* Also, *Nouvelles Recherches sur l'Imprimerie.* Paris, 1840.

‡ "We see the levity and inconstancy of men's judgments, which, till a matter be done, wonder that it can be done, and, as soon as it is done, wonder again that it was no sooner done."—BACON. *De Augmentis*, lib. i.

We may take later examples. During the middle ages men were long accustomed to carve inscriptions in stone, to inscribe the brasses of tombs, and to cast bells with inscriptions on them In this last operation the letters and ornaments were in reverse, and were cut in the outer mould or cope, the clay of which was softened for the purpose; or they were formed in wax, and fixed on the clay thickness before making the cope. If the latter had been adopted, the separate letters in reverse must have been *composed* as the printers call it, and we thus have another of the essential steps in the art of printing in movable types presented to men's eyes, but withheld from their understanding.

It is the same with other great inventions. The directive power of the loadstone is said to have been known to the Chinese as early as the tenth century, and to have been actually used by them as a lode or leading stone in crossing the deserts of Tartary. Gunpowder was also known to that remarkable people. But both inventions were several centuries in finding their way to Europe, and in being applied in a manner the Chinese had but little idea of. Just at the time when the feudal system had done its work, and the towns had risen into wealth and importance, and national or kingly power was required for the stability of the people, the barons, who, shut up in their strongholds, resisted the argument of nationality, could not resist the more solid argument of a cannon-ball. So again, when the national prosperity required a wide extension of commerce, the compass lent itself to that extension just at the time when it was wanted. The same remark applies to railroads and locomotives. When our old modes of conveyance were inadequate to the wants of the community, railways and locomotives were introduced in spite of determined opposition. The electric telegraph was introduced a little before its time, and it had well-nigh failed in consequence. An experimental line had been laid down on the Great Western Railway from London to Slough. It proved its capacity for work by the transmission of messages; but so little effect did it produce, that the proprietors were under orders to remove it as a useless encumbrance, when a singular circumstance arose. A man who had to support a poor old housekeeper went down to see her, with a bottle of porter in one pocket and a bottle of poison in the other. He mixed the two together, and she fell dead at his feet. He returned to London by the only line that had an electric telegraph; and while on his way up to town, a message was flashed along the wires to London to arrest a man dressed in a particular fashion, on a charge of murder. The man was arrested, tried, and executed; and electric wires were not long in being stretched over the earth's surface, and sunk in the sea to enable people and nations separated by distance to talk together. It may be said that in all inventions necessity is the parent—that men feel a want and seek to gratify it, and hence the uncertainty both as to the inventor and the time of the invention. Such, however, is not the case. Men may suffer practical inconveniences of all kinds during long years, and even centuries, for want of a particular invention (the compass, for example), and yet the invention does not appear. A careful study of the subject will nearly always explain to us why the invention was delayed so long; and I cannot help thinking that such an inquiry would be worth making.

In the third place, as to the effect. The effect of an invention upon ourselves depends very much upon the circumstances whether we grow up to the invention, or the invention grows up to us. In the former case we take things as a matter of course, just as we do sunrise or the succession of seasons. The most complicated invention that we grow up to sinks down to the level of our daily experience, and we are apt to slight, or at least to disregard it. When, however, the invention grows up to us, and we trace it through its uncertain infancy, its more hopeful youth, its vigorous maturity, we have generally to pass through the reasoning process by which these results have been obtained; and we thus become much more impressed with a new, than with an old invention, though of equal or greater merit. For example, young persons regard the electric telegraph very much as a matter of course. They have grown up to the invention, and think the sending a message by such a channel a very ordinary affair. I confess that is not my feeling. I go into an office in London and say I want to ask a question in Edinburgh, upwards of 400 miles off. I put my question, and the clerk requests me to look at the paper for a few minutes while he sends my message. There is a little clicking noise, and then all is quiet. In a few minutes a bell rings, there is another clicking noise, and there is the answer to my question, both question and answer having travelled 400 miles during this short space of time. I was once in a room at Manchester where the wire was open all through the 1,500 miles to St. Petersburg, and Manchester conversed with the Russian city with the greatest ease. All this is even now so strange that I have to go over the steps of the process every time I witness such a result.

But as I have already said so much about the art of printing, I will illustrate the effects of a great invention by its means. Every child who reads knows something of the value and effect of printing. Let us then try to realise the condition of society when there were no books. The ancient Romans had books, or rather rolls, of parchment or papyrus. They had ink of various colours, and several modes of writing. They had a highly-polished literature, and an intellectual, though comparatively small, reading public in every town and camp of their vast empire. When at the beginning of the fourth century prodigious swarms of barbarians invaded the empire, they found a learned, artistic, over-refined, and physically weak people. These rude invaders at once associated weakness with learning, and despised it. Procopius has preserved a remark of one of these barbaric chiefs. He said, "If my son is accustomed to tremble under the rod of a pedagogue, he will never look on a sword or a spear with a steady eye."

The first barbarians that settled down in the country they had conquered were themselves invaded by barbarians still more fierce and warlike, who, after repeated struggles, gained possession of the fairest portions of the empire. But during this time letters and learning, arts and sciences, were swept away, and the profession of arms was alone held in esteem.

Historians mark as the most calamitous and afflicting period of the world's history the 176 years which elapsed between the death of Theodosius the Great (A.D. 395), and the establishment of the Lombards in Italy (A.D. 571). The ruin occasioned by the barbarians is compared by contemporary writers to the havoc of earthquakes, conflagrations, and deluges. Whole cities became depopulated; fertile lands changed into swamps; and desolation and woe everywhere prevailed.

Towards the close of the sixth century, the barbarians having devoured the land and its inhabitants, and having become weary of devouring each other, settled down upon their conquests. Few, indeed, were the remaining traces of Roman polity, jurisprudence, art and literature, to guide the new communities. It seemed as if every trace of vital Paganism had to be stamped out of the world before society could frame itself anew, or Christianity make any progress. It is probable that a rude warlike people, settling down under similar circumstances in different parts of Europe, would adopt a similar system of government, based on a military polity. On partitioning out the conquered territory, every freeman or soldier on receiving his share bound himself to appear in arms against the enemy of the community when summoned by his chief. In this way originated the feudal system which prevailed in Europe during some centuries. The power of the sovereign was very limited, and the Church acquired influence very gradually.

During several centuries ignorance hung like a thick cloud on the land. Persons in the highest rank could neither read nor write, and they despised those who could. Documents were made legal by the sign of the cross, as practised by the illiterate at the present day. Many of the clergy did not understand the breviary which they daily recited, and some of them could scarcely read it. Many dignitaries of the Church could not even subscribe the canons of the council in which they sat as members. King Alfred complained that from the Humber to the Thames there was not a priest who understood the liturgy in his mother tongue, or who could translate the easiest piece of Latin; that from the Thames to the sea the ecclesiastics were still more ignorant. Even Alfred himself, though reputed the best scholar of his time, found it difficult to translate the pastoral instructions of St. Gregory, on account of his imperfect acquaintance with Latin.

One cause of this deep ignorance was that Latin was no longer a living language, and there were no books in the modern tongues. Latin was used in the services of the Church, and was the diplomatic language of the Court of Rome. It was also used in charters, legal instruments, and public correspondence. Though imperfectly known, men did not seek to improve their knowledge by a study of the best Latin writers. Indeed, it would have been difficult to have done so, under the great scarcity of Latin authors, and the feeling that such books ought not to be read. The few copies that did exist were in the monasteries, and were almost entirely forgotten from the sixth to the eleventh centuries. During this period there were no authors, except a few scanty chroniclers and writers of trifling legends. Papyrus had gone out of use, and the manufacture lost; paper was not yet invented, or at least not introduced;* so that parchment was about the only writing material, and this was scarce and costly. The consumption of meat was not large, and the skins of the slaughtered animals were caught up by the tanner. Hence, when parchment was required, it was common to erase the writing from an old manuscript, and in this way valuable works have frequently been lost. But there was as little demand for writing as for reading. Many a monastery had but one missal, and rare indeed was it to meet with a complete copy of the Scriptures. Portions of them belonged to different monastic libraries. The few privileged places that had all the books, had them in separate portions, not transcribed continuously into one volume as in our *Bibles*, for that term was unknown until about the thirteenth century, previous to which such a volume was distinguished as the *Bibliotheca*, or the *Pandectae*, i.e. "embracing all." In process of time each monastery or priory instituted a *Scriptorium* with its staff of transcribers, who kept up the scanty supply of books, of the Gospels chiefly, but also of the Bible. The slowness of the work may be judged of by the fact that fifty years of a man's life have been occupied in transcribing the Bible. Prayers were even put up that the transcriber of a single volume might be able to complete it in his lifetime.

Books, thus slowly produced, were costly. The transfer of a book from one person to another was effected with as many formalities as the sale of a piece of land; and the loan of a book often required the deposit of a sum of money, and the personal guarantee of some one of importance for the safe return of the precious commodity. The Countess of Anjou paid for a book of homilies 200 sheep, and 5 quarters each of wheat, rye, and millet. Even so late as 1451, or three years before Gutenberg began his experiments on printing at Strasburg, Beccatello wrote to Alphonse, King of Naples, entreating him to purchase a Livy then on sale, and describes the several books as being very handsome, and the price of each book 120 crowns of gold (about £100 sterling).

In this rapid sketch I have rather left it to the reader's imagination to realize the effects of printing, by thus glancing at the condition of society in the absence of printed books. It would be a long history to relate the steps by which men gradually emerged out of ignorance into intelligence. There were the Crusades, with their long train of consequences; the growth of towns and the privileges they gradually acquired and secured by charters; the growth of the national power; the founding of colleges and schools and the general revival of learning, art, and science. It was just at the time when the minds of men had been awakened, and a cheap and easy method of multiplying books was required to promote and extend progress, that the art of printing with movable types stepped in to supply the want. We know but little as to the prices charged for their books by the early printers. We know they were their own type-founders, illuminators, binders, and publishers, but we do not know their publishing price, if, indeed, they had any; for it is likely each copy of a book was bargained for as a horse or cow would be, the seller seeking to raise, the buyer to lower, the price. There is a statement that in 1458 books were only one-fifth the cost of the manuscripts prepared just before the invention of printing; but the decline in price must have been rapid as printing presses became multiplied. Gutenberg's *Catholicon* of 1460, which was sold in 1465 for 41 gold pieces, produced only 13 in 1475.

Similar historical details, and a similar treatment, might be connected with other great inventions, which, treated in this way, might afford matter for new and interesting speculations. At any rate, the hints thus thrown out will not, it is hoped, be considered an inappropriate introduction to a work that deals so largely with invention.

C. T.

King's College, London,
March, 1866.

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* [illegible]

CYCLOPÆDIA OF USEFUL ARTS,

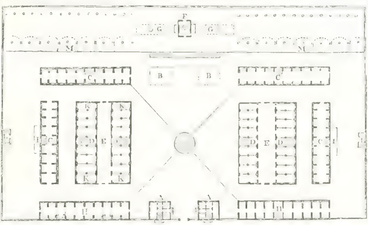
Mechanical and Chemical,

MANUFACTURES, MINING, AND ENGINEERING.

ABATTOIR (from the French verb *abattre*, to fell or knock down), a term applied to an establishment situated on the outskirts of a large town, where animals are slaughtered for supplying the inhabitants with meat. In ancient Rome, a corporation of butchers had the privilege of supplying the city with meat. They had been for a long period scattered over different parts of the city, but were at length collected into a single quarter. In the reign of Nero, the grand market, with its slaughter-houses, formed a magnificent establishment. In Paris, from time immemorial, a corporation of butchers had the privilege of purchasing cattle and supplying the city with meat; but here the policy of the Romans ceased to be imitated, for the cattle, purchased at the markets of Sceaux or Poissy, were driven through the public streets to the butchers' shops, before which they were slaughtered and prepared for sale, the refuse animal matters being stored in large tubs; the whole arrangement being as dangerous to the persons and health of the inhabitants as it was offensive to the sight.

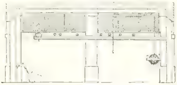
A remedy for these evils had long engaged the attention of the government. The butchers themselves were most energetic in opposing a change; but at length the strong hand of the Emperor Napoleon put down all opposition, and, by a decree dated 9th February, 1810, it was ordered that five abattoirs should be erected in the neighbourhood of Paris at the expense of the city, under the direction of a Committee of Architects and Engineers appointed for the purpose. Plans were accordingly prepared, with the assistance and advice of a retired master butcher. Eight years were occupied in carrying them into execution, and they were opened for public use in 1818. Their value was at once appreciated—they freed the city from a disgusting and dangerous occupation, and afforded additional facilities for inspection. As all the cattle slaughtered for the supply of Paris must be driven into the abattoirs, the inspectors can easily ascertain whether the animals are healthy, and in a fit state to furnish food to human beings. Besides this, all the offal and refuse animal matters can be easily collected together, for supplying various trades which are dependent on the slaughter-houses, such as the manufactures of glue, of gelatine, of Prussian blue, of hoof-oil, of blood-manure, &c., whose works are collected near the abattoirs, and thus relieve the city of trades which are as offensive, or even more so than the occupation of the slaughterer.

Fig. 1.



In the abattoir of Roule, the original site was on sloping ground, and the earth excavated during the process of levelling was formed into an esplanade before the entrance, and planted with trees. At the upper part of the slope the earth is supported by arches, the vaults of which serve as coach-houses and stables, and above is a spacious terrace also planted with trees. Fig. 1 is a ground-plan of this abattoir, which may be taken as the type of all the rest. At the entrance are two small buildings A A, the residences of the inspectors, superintendents, porters, &c. When the animals first arrive at the abattoir, they are driven into the open spaces B B, where they remain until the butchers arrive and take them to the lay-stalls C C. These edifices have about thirty feet of internal width. On one side the oxen are arranged, and on the other side the sheep and calves. There are racks and bins for fodder, and a large water-trough. The upper stories of these buildings are divided into small rooms, which are used as granaries, one of which is appropriated to each butcher. D D are ranges of slaughter-houses, separated from each other by a court-yard. Each slaughter-house is about 16½ feet wide by 32¾ feet long, and is furnished with two entrances, one by which the animals are introduced, and the other, on the external front, for removing the carcasses. There is also a cock for supplying the water required in washing, a channel sunk below the paved floor, a windlass and a pulley for drawing up the carcass to be flayed, and a couple of poles fixed into the wall at one end, seven feet from the ground, and supported at the other end by a stirrup iron, for hanging up the carcasses of the oxen until they are ready to be removed. Pegs and hooks are fixed to the roof and walls for hanging up the calves, sheep, and lambs (see Fig. 2). The floors are paved with stone, and the joints well cemented. Small openings in the lower part of the door admit the air, and a large space is also left open below the roof, so that the air may circulate freely. The roof projects about 10 feet beyond the external walls, (see Fig. 3) for the purpose of sheltering the interior from the sun, and also to afford a cover for the carts which are sent to convey away the meat. This arrangement of the roof and door keeps the interior of each slaughter-house some degrees cooler than the external air, which is found to be far more effectual in preserving the meat from blow-flies in summer than by enclosing it in canvass, perforated zinc, or other similar contrivances.

Fig. 2.



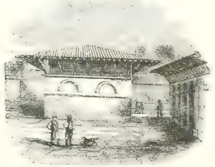


Fig. 3 SLAUGHTER-HOUSES.

An abundant supply of water is required for every part of the abattoir. This is furnished by a well, and is pumped up by a steam-engine F, into reservoirs G G, Fig. 1.

The superfluous fat and fatty parts of the animals which cannot be used as food, are melted down for the purposes of the tallow-chandler, soap-maker, &c. This is done in the melting-houses H, which contain coppers of the capacity of from ten cwt. to forty cwt. of tallow. Under the same roof are places where tripe is prepared for sale. The offal and refuse animal matters are collected from the various lay-stalls, slaughter-houses, &c., every day into the yard or shed I (Fig. 1), which is paved, and the joints between the stones made tight with cement. This court is cleared out and well washed if possible every day, to prevent any ill odour. The other letters of reference in Fig. 1 are K warehouses, L lieux d'aisance, M vaults under the terrace, N coach-houses and stables.

In addition to these arrangements, each abattoir is furnished with a capacious sewer for receiving the various liquid animal matters from the lay-stalls, slaughter-houses, &c. The drains which lead into it are furnished at their upper part with a grating, sunk a little below the pavement, fitting into a short, wide tube, of which the lower extremity dips into a basin, and thus acts as a valve or stink-trap, Fig. 4, and prevents gas from the sewer from rising up, while the liquid matters which pass through the grating fall into the basin, and then overflow into the drain.

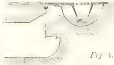


Fig. 4.

The revenues of the abattoirs are considerable. The butchers are charged six francs per head for all the oxen slaughtered; which, on 75,000 or 80,000, oxen, produces an annual revenue of nearly 500,000 francs. After paying all expenses, a considerable revenue goes to the municipal purse. The new system is also far more economical to the butchers themselves than the old method. It has been found also that by withdrawing the slaughterers from the public gaze, and insisting upon habits of neatness and order, the manners of this class of men have been greatly improved.

Abattoirs have recently been erected in London, in connection with the new Metropolitan Cattle Market at Holloway. There are two, at the west end of the bullock lairs, used for slaughtering bullocks. The slaughter-house is 38 feet square, with four pairs of balks running parallel with the front, where *travellers* are attached for holding the carcasses; they run on iron plates screwed to the top of the balks; two other beams are fixed transversely over these, about six inches apart, upon which the running tackle belonging to two windlasses for hoisting the carcasses traverse. These are fixed about 12 feet from the end wall, to give space for one slaughterman to dress a bullock while his fellow-workman may be engaged in killing another.

In killing a bullock, a rope is put round the animal's neck, and is passed through one of four rings placed in the wall, two feet from the ground, and secured to an iron cleet. One hundred bullocks can be hung in each slaughter-house. In the centre of the roof is a louvre for the escape of steam and heated air; in the front and back walls are louvres to assist the ventilation. By these means the carcass cools more quickly in summer, and the meat can be kept about twenty-four hours longer than when killed in the ordinary slaughter-houses. The light is admitted by a skylight facing the north, and for economy of space the doors are made to slide. The blood-tank is placed in the washing-place A (Fig. 5), to which it is conveyed by wide glazed earthenware pipes.

The washing-place A is fitted up with coppers for boiling water, enamelled slate divisions for the hides, table and sink, and hooks for hanging paunches, &c. The walls of this place, as well as the slaughter-house, are faced with glazed Stourbridge bricks to the height of four feet, to allow the blood to be washed off. Water is laid on where required; a stand-pipe, with a flexible hose, is placed in one corner of the slaughter-house. Behind the washing-place is the killing-pound B, where the bullocks are kept previous to being killed: the size of this pound has been circumscribed in consequence of the proximity of the bullock lairs (in which space is provided for the lairage of about 3000 bullocks), and which the slaughtermen have the advantage of using by the payment per head of a small toll, and thus only paying for the poundage of his beasts according to the requirements of his business, when his own pound may happen to be full. The dung-pit is away from the building. Bye-laws of the Corporation require that the blood, offal, &c., shall be cleared away several times in each week.

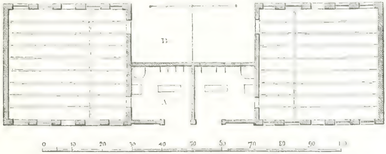


Fig. 5. PLAN OF LAIRS, SLAUGHTER-HOUSES, ETC.

Fig. 6. ELEVATION OF SLAUGHTER-HOUSES AT HOLLOWAY.

A meat market has also been erected in connection with, and in immediate proximity to, the slaughter-house.

The private slaughter-houses are differently arranged. The blood is received from the pipes in tubs, iron rails and hooks are fixed for hanging sheep, for which purpose a larger proportionate width is given in the slaughter-house, and an additional killing pound for sheep is provided.

ABUTMENT—See BRIDGE.

ACETIC ACID (from the Latin *acetum*, vinegar) is important in a manufacturing point of view from its being the sour principle of vinegar. This acid occurs ready formed in some plants, and is produced during the spontaneous fermentation of many vegetable and animal juices. All liquids containing alcohol are capable of passing into the state of vinegar; and hence the manufacturer finds it convenient to employ those liquors in which the vinous fermentation is complete,—such as wine, beer, &c. When these liquids are exposed to the atmosphere, at a certain temperature, a new chemical change is induced, whereby oxygen is absorbed, and the alcohol gradually passes into acetic acid. This acid, as it exists in combination with certain bases, is composed of 4 atoms of carbon, 3 atoms of hydrogen, and 3 of oxygen; but in this state, which is called *anhydrous*, or without water, it has never been obtained separately. In combination with one atom of water, it forms what is called *glacial* acetic acid, from the circumstance of its freezing at a temperature of about 45°. This acid may be represented by the formula, $C_4 H_3 O_3 + HO$; that is, 4 atoms of carbon, 3 atoms of hydrogen, 3 atoms of oxygen, plus 1 atom of water. Now, as alcohol is composed of $C_4 H_6 O_2$, its conversion into anhydrous acetic acid will be seen to consist in the abstraction of two atoms of hydrogen, and the addition of two atoms of oxygen. Or, if we take 100 parts of alcohol, and 100 parts of hydrated acetic acid, we get—

52.6 carbon.	40.6 carbon.
12.9 hydrogen.	6.6 hydrogen.
34.5 oxygen.	52.8 oxygen.
100.0 parts of alcohol.	100.0 parts of hydrated acetic acid.

Hence it will be seen, that acetic acid contains the same elements as alcohol, but in different proportions; there being less carbon and hydrogen, but more oxygen. It was formerly supposed that this change was brought about by the alcohol being deprived of a portion of its carbon and hydrogen, while the oxygen remained the same. More recent inquiries have proved that no carbonic acid is formed during the process; but that a portion of the oxygen of the atmosphere combines with a portion of the hydrogen of the alcohol to form water. The alcohol, thus partially deprived of its hydrogen, forms a new compound, named *aldehyde*, which contains the same proportions of carbon and hydrogen as acetic acid, but less oxygen; the deficient quantity of oxygen being afterwards supplied by the atmosphere.

The conversion of alcohol into acetic acid may be shown by a beautiful experiment,—the basis of a manufacturing process adopted in Germany. When vapour of alcohol is brought into contact with a black powder obtained by mixing muriate of platinum, potash, and alcohol, vinegar is rapidly formed; the powder absorbing and condensing the oxygen of the atmosphere, so as to enable the alcoholic vapour to combine with it. The arrangement is as follows:—Under a large glass case a number of earthen dishes, containing dilute alcohol, are arranged on shelves, one above another, and over each dish is suspended a portion of the moist platinum powder. A temperature of from 68° to 86° Fahr. is maintained, and the evaporation of the fluid is promoted by hanging several strips of porous paper in the case with their lower edges dipping into the dishes, whereby a greatly increased amount of evaporating surface is obtained. In a few minutes the mutual action of the platinum powder and the alcohol will cause an increase of temperature, accompanied by the formation of acid vapours, which condense on the sides of the case, and trickle down to the bottom. This action continues until all the oxygen in the air of the case is consumed; but the action is renewed by a fresh supply of air. If the case contain 1,000 cubic inches of air, this will suffice to oxidize 110 grains of absolute alcohol, and will produce 122 grains of anhydrous acetic acid, and 64½ grains of water. The platinum powder does not waste, and may, therefore, be used over and over again.[1]

In the general process of vinegar-making, some cheap ferment is usually made to take the place of the platinum powder in the above experiment. There are many substances containing nitrogen which answer this purpose, such as gluten, mucus, vinegar itself, or substances containing it, such as yeast, sour dough, sour beer, but especially sour bread soaked in vinegar. These substances, being in a state of inodorous putrefaction, decay, or oxidation, draw the alcohol into the circle of their decomposition, just as decaying wood causes fresh wood around it to assume the same condition. When the alcoholic liquor, mixed with the ferment, is exposed at a proper temperature to the atmosphere, the ferment is supposed to absorb oxygen from the air, and to transfer it to the alcohol. The liquor soon becomes turbid; slimy particles form in it, and collect as a scum on the surface; this scum thickens, and, after a time, falls to the bottom. The Germans call it the *vinegar mother*, and use it for the purpose of exciting acetification in fresh liquor. The temperature of the mass rises, and diffuses a peculiar aroma over the place. When all the alcohol has been converted into acetic acid, the action ceases, the temperature declines to that of the surrounding air, the liquor becomes bright, and may be drawn off as vinegar fit for the market.

All substances, then, that can be made to undergo acetous fermentation, either because they contain sugar, or that sugar is formed in them from starch, can be employed in the manufacture of vinegar;—as, for example, in malt, the starch is converted into sugar by the process of mashing, and the sugar is converted into alcohol by vinous fermentation.—[See FERMENTATION.]

According to the substance employed, the variety of vinegar receives its name in commerce, as—1. *Wine vinegar*, which is prepared from wine, and contains acetic acid, tartaric acid, and a minute portion of acetic ether, to which the pleasant aroma of this kind of vinegar is due. 2. *Artificial Wine vinegar*, or *Alcohol vinegar*. This is prepared from spirits, and consists almost entirely of acetic acid, water and a small portion of acetic ether. 3. *Fruit vinegar*, or *Cider vinegar*, from the fermented juice of apples; this vinegar contains, besides acetic acid, malic acid, which is a source of acidity in apples and many other fruits. 4. *Beer*, *Malt* or *Corn vinegar*, formed from the extract of malt, and contains, in addition to acetic acid, nearly all the constituents of beer, such as the phosphates of lime and magnesia, gum and an extractive substance which imparts colour, and causes the vinegar to froth on being shaken. There is a fifth variety of vinegar produced by the destructive

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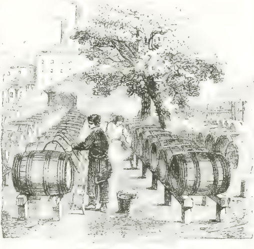
(1) Ure's Dictionary of Arts and Manufactures.

distillation of wood, but as the formation of this acid differs from that of acetic, we must refer to PYROLIGNEOUS ACID, in the APPENDIX, and to WOOD, Cyc.

Vinegar is manufactured by one of two distinct methods, called the *slow* and the *quick method*, the one requiring months, and the other days for the completion of the process. We will first describe the manufacture by the slow method.

In countries where much wine is grown, vinegar is manufactured chiefly or entirely from the inferior sorts, and from the refuse of the wine-grower. Orleans in France is celebrated for its vinegars. The acetous fermentation is carried on in casks, called *mothers*, of about the capacity of an old English hogshead, laid horizontally on tressels, in ranks close together. Each cask has two holes at the upper part of the front end: one two inches in diameter, for pouring in the charge and drawing off the vinegar, the other of smaller size, for allowing the air to escape while the charge is being poured in by means of a funnel, which fills the large hole. The charge occupies about two-thirds of the cask. The wine is clarified before being poured into the casks, by being strained through a tun filled with chips of beechwood, well pressed down. Should the vinegar not be perfectly clear, it is filtered in a similar manner. The fermenting room is kept at a steady temperature of 86°, by means of brick flues, or hot-water pipes, running along the sides of the floor, the furnace being on the outside to prevent any contamination of the vinegar from smoke or dust. The air of the fermenting room is renewed by moderate ventilation, but the air holes are shut in windy weather, or when the temperature is too low. To see whether the fermentation is complete, a white stick, bent at one end, is plunged into the liquor. If on drawing it out it be covered with a white, thick, pearly froth, the acetification is considered complete; if the froth be red, it is not complete, in which case fresh wine is added, or the temperature is raised. This method occupies several weeks.

In the United Kingdom, vinegar is almost exclusively manufactured from malt. A sweet wort is obtained by mashing the malt as in brewing; [See BREWING;] a ferment is added, and the *wash* or *gyle*, as it is then called, is acetified either by *storing* or *fielding*. By the first method, casks containing the wash are arranged in close rooms, heated by steam-pipes or stoves. By the second method, the casks, each containing rather more than 100 gallons, are placed on their sides in the open air, with the bung-holes up, and arranged in long parallel rows, two or more deep, with narrow walks between, forming what is called a field. These casks are supplied by means of a flexible pipe or hose, in connexion with the great wash-tun in the brew-house. The wash usually requires several months for its complete acetification, during which time the bung-holes are left open in fine weather, but covered with a tile during rainy weather. When the acetification is complete, the vinegar is removed from the casks by means of a syphon into a shoot on the ground, whence it is pumped into a store vat within doors. Before the vinegar is fit for the market, it is clarified by being passed slowly and repeatedly through large vats, called *rapes*, which contain a compact heap of the stalks and skins of raisins, called *rape*, the refuse of the British wine manufacture. In order to obtain a constant supply of this article, the malt-vinegar making is associated with the manufacture of British wines, called *sweets* by the excise.[1]



[illegible] VINEGAR FIELD.

In some places a solution of sugar is used in vinegar making, instead of an infusion of malt. One recipe directs 1 part of sugar to be dissolved in 6 parts of water, to which 1 part of brandy or other strong spirit is to be added together with a little yeast. This mixture is poured into a large cask with the bung-hole left open, and kept at a temperature of from 70° to 80°. The acetification will be complete in a month or six weeks, when the clear vinegar may be drawn off. Liebig recommends a mixture of 100 parts water, 13 brandy, 4 honey, and 1 of tartar; or 120 water, 12 brandy, 3 brown sugar, 1 tartar, and half a part of sour dough, to be left for some weeks in a warm place.

It is not necessary to give any further details respecting the slow method, which is very inferior to the quick method now to be described. This has been carried to such a point of perfection, that it is scarcely possible to imagine any further improvement; for the highest aim of the manufacturer, the conversion of the alcohol into acetic acid without loss, and in the shortest possible time, seems to have been completely accomplished. This method originated with Boerhaave, long before the true chemical theory of the formation of vinegar had been obtained. He employed in the manufacture two large casks of the same size, each open at the top, and placed upright on the frame of the vinegar-room. These vessels were filled with the stalks and husks of grapes, and

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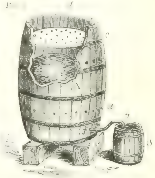
(1) A detailed account of Messrs. Beaufoy's Vinegar and British-Wine Factory will be found in one of Mr. Dodd's amusing Factory Visits, in the Penny Magazine, No. 679.

one was then entirely filled with the alcoholic liquor combined with the acid ferment, and called the *vinegar mixture*, and the other cask was only half filled. After 12 hours, half the liquor was drawn out from the full cask, and poured into the other, and this process was repeated every 12 hours. The acetification proceeded with great rapidity in the vessel that was only half full, as was evident from the escape of suffocating fumes of vinegar; the temperature within it far exceeded that of the vinegar room, while in the full cask it was scarcely if at all higher. An improvement on this method consisted in changing the liquors in the two casks every 3 or 4 hours instead of 12, and it was found that in the course of 14 days, such a vinegar was obtained as would have required some months by the slow method. The effect of this contrivance will be evident, when it is considered that every particle of the alcohol in the mixture must be brought into contact with the oxygen of the air, in order to be converted into vinegar, and that the porous mass formed by the grape husks presented an enormous surface to the air in the half filled cask, so that in slowly filtering through it, the mixture was broken up and divided, and the points of contact with the air multiplied to an indefinite extent. In the full cask, on the contrary, the air was in contact with the liquid only at the top of the cask; hence it will be understood why the acetification proceeded much more slowly in the full cask than in the one only half filled, for in the latter case the surface of the liquid was covered by a wet acid spongy mass full of air, and in filling it up, this mass was well washed of its acid particles, and the air renewed. The heat, also, which by the old method was maintained at great expense of fuel, was by the new method generated during the rapid acetification of the mixture, the heat thus liberated being usefully employed to maintain the temperature of the mixture. For example, in converting 10 lbs. of alcohol into vinegar, the same amount of heat is liberated, whether the change be slow or rapid; but in the one case it is distributed over a larger portion of time—say fifty days, and that 500° of the heat of temperature is set free. In such case there would be an accession of heat to the mixture, amounting to only 10° per day, and this would probably be carried off by the surrounding air. But if the fifty days were by the quick method reduced to ten, the mixture would have the heating effect of 50° per day; and if this 10 days were reduced to 1 day of 12 hours, it would have the whole 500° in that time, which would be at the rate of 41$\frac{2}{3}$° per hour, which could not all be dissipated into the surrounding air, so that the mixture could be maintained at a tolerably high temperature without any or much assistance from artificial heat.

Boerhaave's plan has been carried to its greatest point of perfection by a new method of constructing the casks. They are now made of oak, and are from 5 to 7 feet high, and from 2$\frac{1}{2}$ to 3 feet in diameter, but somewhat narrower at the bottom than at the top. About a foot from the bottom, and just above the syphon *f* used for drawing off the acid liquor, each tub is perforated by holes *a* about an inch wide, and sloping downwards, so that the air may enter without allowing the liquor to escape. Each tub is closed by a cover, with a hole in the centre 2 or 3 inches square. Instead of the grape husks and stalks before noticed, each cask is filled with curled beech shavings; but before they or the casks are used, they are repeatedly scalded with hot water to get out all soluble matters, and when dried, are imbued with hot vinegar. The casks are ranged on wooden frames or brick piers sufficiently high to allow the liquor to be conveniently drawn off.



According to another arrangement the cask, A (Fig. 9), called a *graduation vessel*, is furnished with an inner hoop of beech-wood (*c*), about six inches from the mouth (*d*), supporting a perforated shelf. Through the perforations, which are numerous, cotton wicks are drawn and secured by a knot at the upper extremities; they are just thick enough to allow the liquid poured upon the shelf to pass through and drop from their lower ends. The edges of the shelf are packed with tow to prevent the escape of liquid at the side. The lower compartment is filled with beech-wood shavings nearly up to the ends of the wicks. By this means the vinegar mixture is divided into drops, and thus exposed more intimately to the oxygen of the air of the cask.

The vinegar mixture consists of 20 quarts alcohol, 40 of vinegar, and 120 water; or 15$\frac{1}{2}$ quarts alcohol, 20 vinegar, and 137 water. The water is first heated to 100° or 104°, and then the vinegar and alcohol are added, so that the temperature of the mixture may be about 86° or 90° before it is poured into the casks. From 2$\frac{1}{2}$ to 5 quarts of the mixture, according to the size of the casks, are poured upon the shavings every half hour. The cover is then put on, but the hole in the centre is left open. When all the mixture has filtered through, the liquor is drawn off into the mixing vessel, and a few quarts of alcohol are added; it is passed a second time through the shavings, then drawn off and a smaller quantity of alcohol added; it is then sent through the shavings a third time. The liquor after the first percolation becomes changed into a weak vinegar; after the second percolation it becomes greatly increased in strength; and after the third, it is perfectly good and very strong vinegar. The reason why the alcohol is not added all at once, is, that even under favourable circumstances a portion of the alcohol escapes the acetifying action. Indeed in some cases the manufacturer finds that all his alcohol has disappeared, and that no vinegar has been produced. This may occur when the supply of air has not been sufficient to allow the alcohol to be converted into acetic acid. In such case the alcohol becomes transformed into aldehyde, which being extremely volatile, (its boiling point being 72°,) escapes, and leaves nothing but water in the cask. Hence the supply of air to the cask should be abundant, and this is the object of perforating the cask near the bottom, and having the hole in the cover open. If all goes on favourably, the vinegar is rapidly formed, and the temperature rises. With a vinegar room at 77°, and the mixture at 82°, the interior of the casks will often be 95° or 100°. The internal temperature of the casks should not be less than 95°, or the vinegar mixture will not *breathe* enough oxygen. The escape of heat from the casks is prevented by covering them with paper or linen jackets; the air-holes being of course left open. In general it may be remarked that the higher the temperature, and the larger the quantity of air conveyed in the shortest time to the mixture, the more rapidly is the hydrogen of the alcohol oxidised and vinegar formed. The more alcohol there is in the mixture, the stronger will be the vinegar; but the quantity of alcohol in the mixture ought not to exceed 10 per cent. The temperature must not be below 72° nor above 113°. When fruit or malt vinegar is prepared by this process, the liquor must be as clear as possible, or the shavings will become coated with a slimy substance.[1]

There is another quick process of making vinegar which has been partially introduced into this country. This plan, which was patented in 1824, by Mr. Ham, of Norwich, differs in many respects from the process just described. The apparatus consists of a large vat, in the centre of which is a revolving pump, having two or more shoots pierced with holes so as to cause a constant shower of wash to descend from the top. The lower part of the vat contains the wash, and in the upper part are birch twigs properly prepared and arranged so as not to interfere with the revolving shoots. Between the surface of the wash and the joists which support the birch, is a vacant space of 3 or 4 inches, into which air is let or forced by holes made in the vat. By means of steam pipes the wash is maintained at the temperature of from 90° to 100°, and being kept in motion by the constant action of the pump, it is so fully exposed to the oxygen of the air in trickling through the twigs, that it becomes acetified in the course of 48 hours; but in practice, it is usual to occupy from 15 to 20 days, according to the season and the state of the atmosphere, in obtaining the complete acetification of the charge.

In 1841, a patent was taken out by Mr. Neale, and others, for the manufacture of vinegar from beet root. The roots are reduced to pulp, and the saccharine juice extracted by pressure. Water is added to the juice, and the whole is boiled. It is next cooled to 60°, and fermented with yeast. The fermented wash is pumped into an acidulating vessel, which is a strong vat of the capacity of 24,000 gallons, in the centre of which, near the bottom, is a small inverted dome, pierced with a multitude of holes, and connected with a blowing apparatus outside. The temperature of the wash is maintained by a coil of steam pipe within the vat, and the interior of the vat is divided into several compartments by means of false bottoms pierced with small holes. The cover is furnished with a valve opening outwards, which yields to a slight internal pressure from the air within.

The total number of vinegar factories in the United Kingdom was, a few years ago, only 48, of which the 5 principal were in London. Vinegar is known in commerce by the numbers 18, 20, 22, and 24, which originally represented the number of pence per gallon, at which it was sold; but these numbers now represent merely a certain quality of the article. About 3,000,000 gallons of vinegar are annually manufactured in the United Kingdom, chiefly in London. In the year 1844 the duty on home-made vinegar was repealed, but 3*d.* per gallon was charged upon the vinegar imported from foreign countries, on what is called *proof strength*, which is represented by No. 24, and which, at the specific gravity of 1·0085, contains 5 per cent. of real acid. The strength may be estimated by a species of HYDROMETER, called an *acetometer*, but as the specific gravity of vinegar depends more upon foreign matters than upon the actual quantity of acetic acid contained in it, the best method is to saturate a given quantity of the vinegar with dry carbonate of soda; and the quantity of that salt required for the purpose indicates the proportion of real acetic acid present, 54 parts of dry carbonate of soda being equivalent to 51 of true, or anhydrous acetic acid. Another method is to saturate the vinegar with lime. "The equivalent of carbonate of lime, which is 50, is so near that of acetic acid, as to furnish a ready mode of ascertaining the value of vinegar, or other dilute acetic acid. For this purpose a piece of clean white marble is selected and accurately weighed; it is then suspended by a thread in a proper quantity of the vinegar to be examined, which is occasionally cautiously stirred, so as to mix its parts without chipping the marble; when it is no longer acted on, it is removed, washed, dried, and weighed; its loss is equivalent to the acetic acid."[1] [See APPENDIX.]

Vinegar may be made stronger by exposure to a low temperature, for the aqueous portion freezes first, and may be removed; and the part which remains unfrozen will be found to be greatly increased in strength.

The quantity of real acid in vinegar is difficult to ascertain, from its being often adulterated with sul-

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(1) Chemical Gazette, Vol. i. Rose, Lectures on Organic Chemistry. Otto, Lehrbuch der rationelle Praxis

(1) Brande's Manual of Chemistry, p. 1717.

phuric, nitric, and hydrochloric acids. Indeed the manufacturers are allowed by law to mix one thousandth of sulphuric acid with the weight of the vinegar. The presence of sulphuric acid may be detected by nitrate of baryta, which occasions a white precipitate. Nitric acid is present, if a bit of gold leaf, wetted with hydrochloric acid, be dissolved on gently heating a portion of the vinegar in a watch glass. Hydrochloric acid is present, if a white precipitate be produced on adding a solution of nitrate of silver to the vinegar. Pepper, and other acrid substances used to adulterate vinegar may be detected by neutralising the vinegar with carbonate of soda, when their undisguised pungency will detect them. Vinegar is apt to be infested with flies *(Musca cellaris),* and with animalcules commonly termed *eels (Vibrio aceti);* these may be destroyed by passing the vinegar through a spiral tube immersed in boiling water. Vinegar exposed to the air gradually becomes turbid or *mothery;* it loses its acid, and deposits a slippery gelatinous substance, which when dried resembles gum. The vinegar becomes weak and mouldy as this change goes on.

The use of vinegar as a condiment may be understood from the properties of acetic acid. In its concentrated state, this acid acts on living tissues as a caustic, producing heat, redness, and rapid inflammation of the skin. It dissolves many organic products, such as camphor, gluten, gelatine, gum resins, resins, fibrine of blood, white of egg, &c. When properly diluted, as in vinegar, and used in moderation, it promotes digestion. The property of the acid in dissolving gelatine shows the use of vinegar as a condiment with veal, young meats, and fish. It also assists the digestion of crude vegetables, such as salads. Its powers are heightened by having aromatic or pungent substances dissolved in it, such as chilies or tarragon. Persons who use much vinegar with the view of preventing corpulency, may do themselves much injury, and even engender cancer in the stomach. The *salts of vinegar* sold at the druggists' shops as a reviving scent in sickness and fainting, consist of sulphate of potash impregnated with acetic acid, and scented with oil of rosemary, or lavender.

A pure variety, called *distilled vinegar,* was formerly produced by distilling common vinegar, a plan now almost entirely superseded by mixing pure acetic acid with water. Colour can be imparted to it by means of burnt sugar.

ACIDS (Lat. *acidus,* sour) form a very numerous and important class of bodies in chemistry, and in many of those arts and manufactures in which chemical processes are concerned. Perhaps the most important acid in a manufacturing point of view is the SULPHURIC. NITRIC, HYDROCHLORIC, ACETIC, CARBONIC, TARTARIC, CITRIC, OXALIC, ARSENIOUS, and other acids, are also important objects of commerce.

The common idea of an acid, is a soluble substance possessing the property of *sourness.* The chemist, however, disregards this property, and considers all those substances to be acids which impart a red colour to blue litmus paper, and form stable, neutral and crystallizable compounds with *bases,* such as alkalies and earths, or metals or their oxides. Indeed, all acids are remarkable for their great powers of combination. Many acids are natural or organic products, of very complex structure: these cannot be formed synthetically, that is, by artificially uniting their elements; others are not found in nature, but result entirely from chemical processes. Acids occur in all three kingdoms of nature: phosphoric acid is found in bone; citric and oxalic acids are vegetable products, and chromic and arsenic are of mineral origin. Those acids which are produced by the oxidation of a metal, are termed *metallic* acids.

The states and properties of acids are of the most varied description; some are gaseous, as carbonic acid; others fluid, as nitrous; others solid, as tartaric: some cannot exist except in combination with water or with a base, such as acetic; others exist without either, as anhydrous sulphuric acid. Most of the acids are colourless, but chromic acid is red; some are inodorous, as sulphuric; others pungent, as hydrochloric: some are comparatively fixed, as the phosphoric; others can be converted into vapour at a moderate heat, as sulphuric; others are volatile at all temperatures, as the hydrochloric.

No simple or elementary substance has the properties of an acid. Hence all acids are compounds of two or more elements. When oxygen was first discovered, it was observed that by its union with phosphorus, sulphur, nitrogen, &c. acids were produced; hence it was supposed that oxygen was the principle of acidity, and it was named accordingly *acid-producer,* from *ὀξὺς,* acid, and *γεννάω,* I generate or produce. But when it was discovered that the union of oxygen with an element produced in some cases an alkali instead of an acid, and that muriatic and some other acids contained no oxygen at all, this theory was abandoned, although the name of oxygen was retained.

The union of one elementary substance with another, is termed a *binary compound;* as for example, oxygen with sulphur in sulphuric acid, or oxygen with sodium in soda. Combinations of binary compounds with each other, as of sulphuric acid with soda, are termed *ternary* compounds; three elements being concerned, as in the instance just given, viz. sulphur, oxygen, and sodium. Most of the mineral salts are ternary compounds. Combinations of salts with one another, or double salts, such as alum, are named *quaternary* compounds.

In binary compounds of oxygen which possess acid properties, the name of the acid is derived from that of the substance which combines with the oxygen, with the termination *ic.* When the same element forms two acid compounds with oxygen, the term *ous* is applied to that which contains the less proportion of oxygen, as in sulphurous and sulphuric acids. When these acids combine with bases to form salts, the *ous* of the acid is changed into *ite,* and the *ic* into *ate.* Thus a salt of sulphurous acid is a *sulphite;* of sulphuric acid, a *sulphate.*

This sort of nomenclature served to distinguish these acids and their salts until, as chemistry advanced, an acid was discovered containing less oxygen than the sulphurous, and then a new name was required: it was therefore called *hyposulphurous* acid, and the salt formed with it was termed a *hyposulphite*, (from the Greek ὑπὸ, under;) so also when an acid was discovered containing less oxygen than the sulphuric but more than the sulphurous, it was called *hyposulphuric* acid, and its salt a *hyposulphate*. In some cases acids have been discovered containing more oxygen than those already named with terminations in *ic*: to these the prefix *hyper* (from the Greek ὑπὲρ, over) is attached, as *hyperchloric* acid, and its salts *hyperchlorates*. A similar system is adopted for all analogous acids.

There is a class of acids called *sulphur acids*, in which sulphur takes the place of oxygen. In such cases the names of the corresponding oxacids are sometimes applied to them with the prefix *sulph*; as sulpharsenious and sulpharsenic acids, which resemble arsenious and arsenic acids in composition, but contain sulphur instead of oxygen.

Most acids contain either oxygen or hydrogen; those which contain the former are termed *oxygen acids* or *oxyacids;* those which contain the latter are termed *hydrogen acids* or *hydracids*. Oxygen, as already stated, combines with the same element in various proportions, forming several distinct acids therewith; but hydrogen does not combine with the same element to form more than one acid. In the nomenclature of the hydracids, the names of both constituents are usually given:—thus the acid compound of hydrogen and chlorine is named *hydrochloric* acid, (a more systematic term than the name *muriatic*, formerly applied to it;) the acid compound of hydrogen and sulphur is named *hydrosulphuric* acid, and so on. The salts of these acids are termed hydrochlorates and hydrosulphates. The subject of salts will be taken up more in detail hereafter. The processes concerned in the manufacture of the most important commercial acids, will be found under the respective heads indicated at the commencement of this article.

ADHESION. The force by which two dissimilar substances resist separation, although their contact does not produce any permanent change in them. It is distinguished on the one hand from COHESION, which is applied to a force of the same kind between similar substances, or parts of the same body; and on the other hand from AFFINITY, which acting between dissimilar substances, not only resists their separation, but renders it impossible by mere mechanical force.

The undisguised action of adhesion generally requires one of the bodies to be solid, because if both were fluid they would mix, and the phenomenon would come under the head of affinity. On the other hand, it commonly requires one body at least to be soft, plastic or semifluid if not fluid, for when both are completely solid we know of no case of decided adhesion which is not referable to electrical or magnetic attraction, or the pressure of the air or other surrounding fluid. Two pieces of clean lead, or of glass, adhere independently of these causes, *i. e.* by the action of cohesion; but with dissimilar metals or other hard bodies, however we may press them, no such phenomenon occurs, for the removal of the atmospheric pressure causes them to fall asunder. Hence it would appear that the "attraction of adhesion," as it has been called, is limited to shorter distances than that of cohesion; since two pieces of the same hard solid can be brought near enough to cohere, while two different solids, no harder or more rigid, cannot be brought near enough to adhere. To produce adhesion generally requires one of the solids to be rendered by heat semifluid or ductile, and then its return to a hard state (if not attended with crystallization) does not diminish the adhesion, unless the unequal contractions of the two substances, by the same fall of temperature, force them to separate. Hence the fitness of different cements to join different substances, depends mainly on their equal expansibility by heat. Metals, being more expansible than solids in general, will not adhere to ordinary cements, but require metallic ones (called solders); and each of these does not adhere to all metals indifferently, but only to those having nearly the same rate of expansion. Glass and stones, being both less expansible and less various in their rates of expansion, adhere to a greater variety of substances; and light porous solids, being very little affected by change of temperature, adhere still more generally to those of the same kind which may be softened by heat or liquid solvents, and return to the solid state gradually and without tendency to crystallize. The most universally adhesive bodies (as pitch) are those which retain, even at low temperatures, a certain ductility by which they may readily yield to the various expansions and contractions of the rigid bodies in contact with them; and the rigid bodies most readily made to adhere are the worst conductors of heat; because they cannot undergo very sudden changes of temperature or of bulk, and so allow time for the adhering body to accommodate itself. The non-adhesiveness of animal membranes is very remarkable, and probably a provision for their cleanliness and freedom from foreign matter. Crystallization, by requiring a body while solidifying to obey with rigour certain internal laws of its own, is a great bar to adhesion.

The adhesion of two solids is generally stronger than the cohesion of at least the weaker one. Hence if two pieces of wood be glued, gummed, or pasted together, and then separated, a layer of cement adheres to each; and if there be a bank note in the midst of the cement, it will be split into two layers, simply because its own cohesion is less than that of the cement, or of the wood, or the adhesion between the cement and either wood or paper. [See MORTARS and CEMENTS—SOLDERS.]

The adhesion between a solid and liquid is often greater than a cohesion of the liquid, so that on separating them a film of liquid remains attached to the solid, and it is said to be *wetted*. Aëriform fluids will *wet* as well as liquids. Thus on plunging the finger (or any non-metallic body) into mercury, it does not touch that liquid, but retains a film of air; just as it would retain, in air, a film of water with which it had been wetted. Some few bodies, generally of a fatty nature, adhere to air in preference to water, and thus cannot be wetted by the latter, except in vacuo, or when plunged to a great depth. Iron requires the pressure of a certain small depth of water to remove its air-film, for small particles of it, and even a needle, carefully placed on water, retain air enough to float them. A body plunged from air into a liquid may behave in three different ways. If its attraction for the liquid be such as to overcome both the adhesion of the air and the cohesion of the liquid, it will raise the liquid all round it with a concave slope, as happens with silver dipped into mercury, or perfectly clean glass into water, but such cases are not common. If the attraction for the liquid be not sufficient to overcome the adhesion of the air, the liquid will be depressed, with a convex slope, to that depth at which its hydrostatic pressure enables it to expel the air-film; and yet after once touching the solid, it may adhere thereto with force enough to overcome its own cohesion, and so may wet it. This is the commonest case with water, and it occurs also with platinum dipped into mercury. The third case is when the adhesion of the solid to the liquid being weaker than the cohesion of the latter, it cannot be wetted even though the intervening air-film be expelled. This occurs with iron, brass and cobalt made to touch mercury; and even in such cases adhesion is not absent, and is more easily measured than in any other case. Guyton-Morveau took disks of these metals 1 inch in diameter, and having suspended them from one arm of a balance, and counterpoised them by weights, made them touch the surface of mercury, when it required the addition to the other scale of 115 grains, 142 grains, and 8 grains to detach them. Gay-Lussac found that when such disks can be wetted by the fluid, they always require (with the same fluid) the same force, however different their materials may be, for this does not measure their adhesion but only the *cohesion* of the fluid, a film of which has to be torn from the rest. But in the case of mercury and metals wetted by it, Morveau found various forces necessary to detach them, because *affinity* is here concerned, for the adhering film is not pure mercury, but an amalgam of the two metals, and the force measured is either the cohesion of this amalgam, or its adhesion to the pure mercury, or to the more liquid amalgam left behind. He found these forces nearly proportional to the affinities of the metals for mercury, or the readiness with which they combine with it; and adhesion may doubtless be considered proportional to, or even identical with that kind of affinity to which the term affinity is most proper, because it acts most between bodies having some resemblance; but both this and adhesion are totally independent of the force commonly called affinity by chemists, which acts most between bodies widely differing from each other. This distinction must be borne in mind, and for this purpose, besides the difference above mentioned there are two others equally broad and important: the affinity that bears a relation to adhesion produces compounds whose properties are in every respect *intermediate* between those of the ingredients, as alloys, solutions, &c.; but the other affinity produces compounds with new properties unlike either of the ingredients, as oxides from a gas and a metal, salts from acids and alkalies, &c.; and lastly, the former kind of affinity produces compounds in which the proportions of the ingredients may vary, as sugar and water in syrup, copper and zinc in brass, &c.; while the other kind leads to definite compounds, whose proportions are always the same. [See Affinity. See also Appendix.]

For a further account of the effects of the adhesion of liquids to solids, see Capillary Attraction.

ADIT, a passage or entrance, (Latin *aditus*, from *ad-ire*, to go to.) See Mine.

ADJUTAGE, See Hydraulics.

ADZE or **ADDICE**, a cutting tool or percussive chisel with a thin arching blade, and its edge at right angles to the handle. In the axe the edge is in the same plane with the handle. These tools are always used with percussion, and hence differ from chisels, which act by pressure. The axe differs from the adze in being a splitting wedge, not a cutting instrument; for if driven into a block of wood as at *a* (Fig. 10) it will split it into two parts through the natural line of the fibres, leaving rough uneven surfaces, and the rent will precede the tool. A similar effect will be produced on removing a stout chip from the side of a block of wood with the hatchet, adze, or paring chisel. So long as the chip is too rigid to bend to the edge of the tool, the rent will precede it. If the instrument is thin and sharp, so that the shaving can bend to the tool, the wood will not split; it will be *cut*. In paring tools, one face of the wedge or tool is nearly parallel with the face of the work. In tools ground with only one chamfer this position not only assists in giving direction to the tool, but also places the strongest line of the tool in the line of resistance, or of the work to be done. Thus the axe or hatchet with two bevils *a*, which is intended for hewing and splitting and not for cutting, must, when required for the purpose of paring the surface, be applied at the angle *a'*, which is a much less convenient and effective position than (*b*) that of the side hatchet with only one chamfer; but for paring a large or a nearly horizontal surface, the side hatchet is inferior to the adze *c*. This instrument is held in both hands by the handle, which is from 24 to 30 inches long, while the operator stands upon his work in a stooping position. The weight of the blade is from 2 to 4 pounds. "The adze is swung in a circular path almost of the same curvature as the blade, the shoulder-joint being the centre of motion, and the entire arm and tool forming as it were one inflexible radius; the tool therefore makes a succession of small arcs, and in each blow the arm of the workman is brought in contact with the thigh, which thus serves as a stop to prevent accident. In coarse preparatory works, the workman directs the adze through the space between his two feet; he thus surprises us by the quantity of wood removed. In fine works he frequently places his toes over the spot to be wrought, and the adze penetrates 2 or 3 inches beneath the sole of the shoe, and he thus surprises us by the apparent danger, yet perfect working of the instrument, which in the hands of the shipwright in particular, almost rivals the joiner's plane. It is with him the nearly universal paring instrument, and is used upon works in all positions."[1]

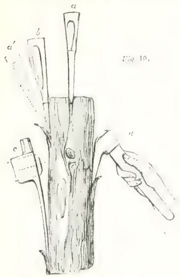

Fig. 10.

The small Indian adze or Bassoolah *d*, instead of being circular like the European adze, is formed at a direct angle of 45° or 50°. Its handle is only 12 or 13 inches long, and the tool is used with great precision by the motion of the elbow joint. It is grasped so near the head that the forefinger rests on the metal, the thumb nearly on the back of the handle, the other fingers grasp the front of it, the nails approaching the ball of the thumb. The wrist is held firmly, the stroke being made principally from the elbow, the inclination of the cutting face being nearly a tangent to the circle described by the instrument round the elbow joint as a centre, the exact adjustment being made by the grasp and the inclination of the wrist, which is soon acquired by a little practice. In this way very hard woods may be dressed for the lathe, with a degree of ease and accuracy not attainable with the small axe used in this country.

In order to grind any one of the adzes just noticed the handle must be removed, and this is easily done, as the eye of the tool is larger externally than internally, as in the common pickaxe, so that the tool cannot fly off when in use, but a blow on the end of the handle easily removes it.

ÆOLIPILE, (from *pila Æoli*, the ball of Æolus, or of the god of the winds,) an instrument formerly used to illustrate the cause and generation of the wind, although it is simply an instrument for converting water into steam. It consists of a hollow ball of metal sometimes made in the form of a human face in the act of blowing, with a slender pipe with a narrow orifice issuing from the mouth of the figure, or inserted into the ball by means of a shouldered screw. The ball being filled with water and the pipe screwed in, the flame of a spirit lamp or the heat of burning charcoal is applied to it, and the water being heated, high pressure steam is formed, which escapes with a great noise from the jet, and with sufficient force to turn round a small vaned wheel opposed to it. Of course the stronger the heat the more elastic and violent will be the steam. Care must be taken that the jet is not stopped up, or the ball may burst and lead to danger. The æolipile is now regarded as only a scientific toy of no practical use, and of very little use to the scientific lecturer, who has better means at his disposal for illustrating the generation and force of steam.

AERATED WATERS, See Carbonic Acid—Waters, Mineral.

AEROSTATION and AEROSTATICS, standing in the air, from ἀὴρ, the air, and ἵστημι, to stand, or στάσις, standing. AERONAUTICS, sailing in the air, from ἀὴρ, the air, and ναῦς, a ship. This subject ought scarcely to find a place in a work devoted to the useful arts, because aërostation has rarely been applied to any useful purpose. The art of flying in the air had been a favourite problem with learned and scientific men from the times of antiquity; but there is no authentic account of the problem having been solved until towards the close of the last century, when the brothers Montgolfier invented a machine which they called a *ballon* or little ball, from which we derive the word balloon. About the same period Cavendish, in England, discovered hydrogen gas, and proved it to be the lightest of all ponderable substances; it therefore occurred to Dr. Black, in 1767 or 1768, that a light envelope filled with this gas would ascend. The experiment was tried by Cavallo, in 1782, but he did not succeed in causing anything heavier than a soap-bubble to ascend. The first balloon that was actually launched into the air, was constructed by Stephen and Joseph de Montgolfier, paper-makers at Annonay, near Lyons. It occurred to them that a thin paper envelope might be employed to confine hydrogen gas in such a way as to cause it to ascend, but they found that the gas escaped so rapidly through the pores of the paper that it could not be depended on. They then conceived the idea that heat might be employed to rarefy the air enclosed in their balloon. The experiment was tried, and a balloon of coarse linen, lined with paper, of the capacity of 23,000 cubic feet, (French,) was found to have a power of lifting about 500lbs. including its own weight. This trial was so successful that the Montgolfiers thought they had completely solved the celebrated problem of flying or sailing in the air. They even suggested that "large balloons might be employed for victualling a besieged town,

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(1) Holtzapffel on Turning and Mechanical Manipulation, vol. ii. London, 1847.

for raising wrecked vessels, perhaps even for making voyages, and certainly in particular cases for observations of different kinds, such as reconnoitring the position of an army,[1] or the course of vessels at 25 or even 30 leagues distance, &c." A public exhibition was made of a *montgolfière*, (as this kind of balloon was called, to distinguish it from the hydrogen-gas balloon,) in the market-place of Annonay, on the 5th June, 1783. The montgolfière was constructed of immense folds of linen buttoned together, and fixed to a frame 110 feet in circumference, the whole weighing about 500lbs., and containing 22,000 cubic feet (French) of air. On applying fire to the opening at the bottom of the balloon, the mass gradually swelled out into a large globe, and was with difficulty prevented from rising. At length it was liberated, and rose with great rapidity. In less than 10 minutes it gained an elevation of 1,000 toises. It then moved in a horizontal line, and gradually descended. The success of this experiment excited the greatest interest all over Europe, especially in Paris, where it was immediately resolved to repeat the experiment with hydrogen gas instead of heated air. A balloon was formed of lutestring, and varnished with India rubber, and on the 23d August it was filled with hydrogen gas, procured by the action of dilute sulphuric acid and iron filings. Considerable difficulty was experienced in filling it; but the gas not having been washed by passing it through cold water, entered the balloon hot, and charged with acid fumes, so that it injured the envelope, and loaded it with moisture. As much as 500lbs. of sulphuric acid, and twice that weight of iron filings were expended before the balloon was completely filled. At length it rose, and was kept suspended at the height of 100 feet above the ground. In this state it was conveyed with acclamations to the Place des Victoires, and about midnight it was transported in silent procession to the Champ de Mars, proceeded by torches, and guarded by horse and foot soldiers; the people were filled with astonishment, and many of them saluted it respectfully as it passed. On the 27th, it was again filled, and allowed to ascend. It remained three-quarters of an hour in the air, and fell five leagues from Paris. On the 19th September, one of the Montgolfiers being in Paris, sent up one of his balloons with an attached car containing a sheep, a cock and a duck. These were therefore the first aërial voyagers. M. Pilatre de Rozier was their immediate successor, but he deemed it prudent to have a rope attached to the balloon and held by persons below, so that he might not be entirely launched into the air. At length, on the 21st November, 1783, this gentleman, accompanied by the Marquis d'Arlandes ascended in a montgolfière at 1.54, P. M. "It rose in the most majestic manner, and when it was about 270 feet high, the intrepid voyagers took off their hats and saluted the spectators. No one could help feeling a mingled sentiment of fear and admiration. The voyagers were soon undistinguishable, but the machine, hovering in the air, and displaying the most beautiful figure, rose at least 3,000 feet high, and remained visible all the time. It crossed the Seine below the barrier of La Conférence; and passing thence between the Ecole Militaire and the Hôtel des Invalides, was in view of all Paris. The voyagers, satisfied with their experiment, and not wishing to travel further, agreed to descend; but seeing that the wind was carrying them upon the houses of the Rue de Sève, Faubourg St. Germain, they preserved their presence of mind, increased the fire, and continued their course through the air till they had crossed Paris. They then descended quietly on the plain, beyond the new Boulevard, opposite the mill of Croulebarde, without having felt the slightest inconvenience, and having in the car two-thirds of their fuel. They could then, if they had wished, have gone three times as far as they did go, which was 5,000 toises, done in from 20 to 25 minutes. The machine was 70 feet high, 46 feet in diameter; it contained 60,000 cubic feet, and carried a weight of from 1,600 to 1,700lbs."

The second ascent was by Messrs. Charles and Robert, on the 1st December, 1783, in a balloon filled with hydrogen.[1] They ascended from the Tuileries at Paris, and in an hour and three-quarters alighted on the meadow of Nesle, 25 miles from Paris. Finding that the balloon was still buoyant, M. Charles ventured alone upon a second ascent. The sun had set, and it was getting dark, but he ascended with great velocity, and reached a height of 2 miles in about ten minutes. The sun rose again to him in full orb, and as he says, "I was the only illuminated object, all the rest of nature being plunged in shadow." A screen of vapour concealed the earth from view, while the moon scattered gleams of various hues over the fantastic and changing forms of the clouds beneath. The air was very cold; the balloon appeared to be fully distended, and upon opening the valve, the gas rushed out like a misty vapour. He descended slowly, and alighted in safety near the forest of Tour du Lay, having travelled 9 miles in 35 minutes. The barometer at the greatest elevation fell to 20.05 inches, giving an elevation of about 9,700 feet. The thermometer sank to 21° Fahr. A short time before this ascent, a small pilot or messenger fire-balloon was launched by Montgolfier; this was found to have proceeded in an opposite direction, which first gave rise to the suspicion of the existence of different currents of air at different heights.

On the 2d March, 1784, M. Blanchard ascended

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(1) This idea was actually practised at the battle of Fleurus in 1794, in which the French, under General Jourdan, gained a decisive victory over the Austrian forces, which has been ascribed principally to the accurate information of the enemy's movements before and during the battle, communicated by telegraphic signals from a balloon sent up to a moderate height. The aeronauts, at the head of whom was the celebrated chemist Guyton-Morveau, mounted twice in the course of the day, and continued about 4 hours each time hovering in the rear of the army. In the second ascent the enemy opened a battery against the balloon, but the aeronauts soon rose to a height above the reach of cannon.

(1) Some idea may be formed of the expense of ballooning at this early period in the history of the art, from the fact that this apparatus cost 400*l.* sterling, one half of which was expended in the production of the gas alone.

from Paris in a hydrogen balloon furnished with wings and a rudder, but they were found to be of no use in guiding the balloon. A parachute or open umbrella was attached above the car, to break the fall in case it separated from the balloon. On the 19th September of the same year, the longest aërial journey yet made was accomplished. The Duke de Chartres, afterwards Orleans, employed Robert to construct a silk balloon. It was 56 feet high, and 36 feet in diameter, its form being a cylinder terminated by two hemispheres. This balloon, which was filled with hydrogen, had a contrivance proposed by Meunier for regulating the ascent and the position of equilibrium of the balloon in the atmosphere. It consisted of a small balloon placed within the principal one, and filled occasionally with common air by means of bellows, or emptied again by opening an exterior valve. The aeronaut would thus be able, without expending the charge of hydrogen gas, either to sink gently through a small space, or to rise again at his pleasure, simply by inflating the inner balloon, or allowing it to collapse. The elevation could thus be adjusted with great nicety. In the first trial of this apparatus, the duke, Messrs. Robert and Charles, and a fourth person, ascended very slowly with a force of only 27lbs., as much as 500lbs. of ballast being stored in the car. At the height of 1,400 feet a storm came on; the thermometer fell from 71° to 61°, and this cold caused the balloon to descend within 200 feet of the tops of the trees near Beauvais. Ballast was thrown out and the balloon rose to an elevation of 6,000 feet, when the gas was found to be 42° warmer than the external air. The duke being very much alarmed for his safety, and anxious to descend, is said to have pierced the lower part of the silk bag with his sword to let out the gas. After many narrow escapes from the dangers of wind and a thunder storm, the balloon descended safely near Bethune, having performed a voyage of 135 miles in five hours.

Passing over several ascents made in France and in this country, we must notice the fate of the first aërial sailor, M. Rozier. On the 15th June, 1785, in company with a young gentleman named Romain, he ascended at Boulogne-sur-Mer with the intention of reversing the experiment performed by M. Blanchard and Dr. Jeffries, who on the 30th November, 1784, crossed the Channel from Dover with the intention of landing at Calais, but after considerable difficulty, were actually deposited in the forest of Guiennes. The arrangements made by M. Rozier were as follows. In order to counteract the fluctuations consequent upon all aërial excursions under the ordinary circumstances, and to obtain the power of increasing or diminishing the weight of his apparatus at will, without the usual expenditure of gas and ballast, he conceived the idea of uniting a montgolfière with a hydrogen-gas balloon. Accordingly, he affixed to the hydrogen balloon, by which the principal part of the weight was to be borne, a small montgolfière, by acting upon which he expected to be able to alter its specific gravity as occasion might require. M. Rozier, however, does not seem to have taken into account the great expansion which a gas undergoes under diminished atmospheric pressure, such as is experienced on ascending to a great height; for as the machine rose the inflammable gas gradually distended the envelope in which it was contained, and then, not having room for further expansion, poured down the tube which formed the neck of the balloon, and speedily reaching the fire used to inflate the montgolfière, became ignited. The whole apparatus was consumed in the air, and the two unfortunate voyagers were precipitated upon the rocks near the sea-shore. A monument was erected on the spot where they fell; it is now in a dilapidated condition, as will be seen from the engraving (Fig. 11) made from a sketch taken a few years ago by a friend of the editor. The ruinous condition of this monument is entirely due to the wanton mischief of the lower orders in the neighbourhood of Boulogne, and is sufficient, we think, to prove that public monuments when left unguarded fare no better in France than in England. The following is an exact copy of the inscription on this monument:—

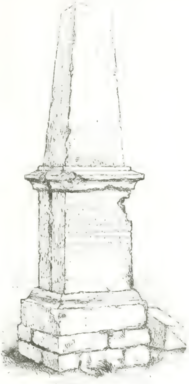

Fig. 11. MONUMENT TO MM. ROZIER AND ROMAIN.

"ICY SONT TOMBEZ, DE LA HAUTEUR DE PLUS DE 5 MILLE PIEDS, À 7 HEURES 45 MINUTES DU MATIN, LES INFORTUNÉS AÉRONAUTES, PILATRE DE ROSIER ET ROMAIN L'AINÉ. PARTIS DE BOULOGNE À 7 HEURES 5 MINUTES DU MATIN LE 15 JUIN, 1785, LE PREMIER TROUVÉ MORT SUR LA PLACE, LE SECOND DONNA QUELQUES SIGNES DE VIE PENDANT UNE OU DEUX MINUTES."

It has been already stated that the French employed balloons for the purpose of military reconnaissance. In the early part of the French revolution a balloon, prepared under the direction of the Aerostatic Institute in the Polytechnic School, and entrusted to the command of two or three experienced officers, was distributed to each of the republican armies. These balloons were of a more solid and perfect construction than the toy machines hitherto exhibited. They were filled by a far more economical method than that before adopted, namely, by passing steam of water through six iron cylinders charged with iron turnings, and heated to redness in a simple kind of furnace; the oxygen of the steam uniting with the iron, while the hydrogen gas being disengaged was first passed through a reservoir of caustic lye before it entered the balloon. By this contrivance a balloon 30 feet in diameter could be filled in about 4 hours at a very moderate expense.

As the aëronautic voyages hitherto undertaken had contributed almost no results to science, the French philosophers were anxious to employ one of the balloons of the Aërostatic Institute, for the purpose of making a set of observations in the higher regions of the air. In July, 1803, Messrs. Robertson and Lhoest had ascended from Hamburg to a height of nearly 3 miles, and had given out a statement of results, the accuracy of which had been called in question. To verify these, and also to settle other interesting points, Messrs. Biot and Gay-Lussac proposed to the French government to make an ascent. Their offer was seconded by Berthollet and Laplace, and Chaptal, then minister of the interior, gave it his warm support.[1] The balloon which had once visited Egypt was delivered to the custody of Biot and Gay-Lussac; and the same artist who constructed it was ordered to refit and prepare it under their direction at the public expense. Besides the usual provision of barometers, thermometers, hygrometers, and electrometers, they had two compasses, and a dipping needle, with another fine needle, carefully magnetized, and suspended by a very delicate silk thread, for ascertaining by its vibrations the force of magnetic attraction. To examine the electricity of the different strata of the atmosphere, they carried several metallic wires, from 60 to 300 feet in length, and a small electrophorus freely charged. For galvanic experiments they had procured a few discs of zinc and copper, with some frogs, to which they added insects and birds. It was also intended to bring down a portion of air from the higher regions, to be subjected to a chemical analysis; and for this purpose a flask, carefully exhausted, and fitted with a stopcock, had been prepared.

The balloon was placed in the garden of the Conservatoire des Arts, and no pains were spared in providing whatever might contribute to the greater safety and convenience of the voyagers. Everything being ready for their ascent, these adventurous philosophers, in presence of a few friends, embarked on the car at ten o'clock in the morning of the 23d of August, 1804. The barometer was then at 30.13 inches, the thermometer at 61.7° Fahr., and Saussure's hygrometer pointed at 80.8°, or very near the limit of absolute humidity. They rose with a slow and imposing motion. Their feelings were at first absorbed in the novelty and magnificence of the spectacle which opened before them; and their ears were saluted with the buzz of distant gratulations, sent up from the admiring spectators. In a few minutes they entered the region of the clouds, which seemed like a thin fog, and gave them a slight sensation of humidity. The balloon had become quite inflated, and they were obliged to let part of the gas escape, by opening the upper valve; at the same time, they threw out some ballast, to gain a greater elevation. They now shot through the range of clouds, and reached an altitude of about 6,500 English feet. These clouds viewed from above had the ordinary whitish appearance; they all occupied the same height, only their upper surface seemed marked with gentle swells and undulations, exactly resembling the aspect of a wide plain covered with snow.

Our voyagers now began their experimental operations. The magnetic needle was attracted as usual by iron; but they found it impossible at this time to determine with accuracy its rate of oscillation, owing to a slow rotatory motion with which the balloon was affected. In the meanwhile, therefore, they made other observations. A Voltaic pile, consisting of twenty pairs of plates, exhibited all its ordinary effects, gave the pungent taste, excited the nervous commotion, and occasioned the decomposition of water. By rejecting some more ballast, they had attained the altitude of 8,940 feet, but afterwards settled to that of 8,600 feet. At this great elevation, the animals which they carried with them appeared to suffer from the rarity of the air. They let off a violet bee, which flew away very swiftly, making a humming noise. The thermometer had fallen to 56.4° Fahr., yet they felt no cold, and were, on the contrary, scorched by the sun's rays, and obliged to lay aside their gloves. Both of them had their pulses much accelerated. That of Biot, which generally beat 79 times in a minute, was raised to 111; while the pulse of his friend, Gay-Lussac, a man of a less robust frame, was heightened from 60 to 80 beats in the minute. Notwithstanding their quickened pulsation, however, they experienced no sort of uneasiness nor any difficulty in breathing.

What perplexed them the most was the difficulty of observing the oscillations of a delicately suspended magnetic needle. But they soon remarked, on looking attentively down upon the surface of the conglomerated clouds, that the balloon slowly revolved, first in one direction, and then returned the contrary way. Between these opposite motions there intervened short pauses of rest, which it was necessary for them to seize. Watching, therefore, the moments of quiescence, they set the needle to vibrate, but were unable to count more than five, or very rarely ten

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(1) Our account of this scientific aerial voyage is condensed from Sir John Leslie's excellent notice contained in the article "Aeronautics" in the Encyclopædia Britannica.

oscillations. A number of trials made between the altitudes of 9,500 and 13,000 feet, gave 7″ for the mean length of an oscillation, while at the surface of the earth it required $7\frac{1}{20}''$ to perform each oscillation. A difference so very minute as the 140th part could be imputed only to the imperfection of the experiment; and it was hence fairly concluded that the force of magnetic attraction had in no degree diminished at the greatest elevation they could reach. The direction of this force, too, seemed, from concurring circumstances, to have continued the same; though they could not depend on observations made in their vacillating car with so delicate an instrument as the dipping needle. At the altitude of 11,000 feet they liberated a green linnet, which flew away directly; but soon feeling itself abandoned in the midst of an unknown ocean, it returned and settled on the stays of the balloon. Then mustering fresh courage it took a second flight, and dashed downwards to the earth, describing a tortuous, yet almost perpendicular track. A pigeon which they let off under similar circumstances afforded a more curious spectacle. Placed on the edge of the car, it rested a while, measuring as it were the breadth of that unexplored sea which it designed to traverse; now launching into the abyss, it fluttered irregularly, and seemed at first to try its wings in the thin element; till, after a few strokes, it gained more confidence, and, whirling in large circles or spirals, like the birds of prey, it precipitated itself towards the mass of extended clouds, where it was lost from sight.

It was difficult in those lofty and rather humid regions, to make electrical observations; and the attention of the scientific navigators was, besides, occupied chiefly by their magnetical experiments. However, they let down from the car an insulated metallic wire of about 250 feet in length, and ascertained, by means of the electrophorus, that the upper end indicated resinous or negative electricity. This experiment was several times repeated; and it seemed to corroborate fully the previous observations of Saussure and Volta relative to the increase of electricity met with in ascending the atmosphere.

The diminution of temperature in the higher regions was found to be less than what is generally experienced at the same altitude on mountains. Thus, at the elevation of 12,800 feet, the thermometer was at 51 Fahr., while it stood as low as $63\frac{1}{2}$° at the Observatory; being only a decrement of one degree for each 1,000 feet of ascent. This fact corresponds with the observations made by former aëronauts, and was probably produced by the operation of two different causes. First, the rays from the sun, not being enfeebled by passing through the denser portion of the atmosphere, would act with greater energy on the balloon and its car, and consequently affect the thermometer placed in their vicinity. Next, the warm current of air, which during the day rises constantly from the heated surface of the ground, must augment the temperature of any body which is exposed to its influence. During the night, on the contrary, the upper strata of the atmosphere would probably be found colder than the general standard, owing to the copious descent of cold portions of air from the highest regions.

The hygrometer, or rather hygroscope, of Saussure, advanced regularly towards dryness in proportion to the altitude which they attained. At the elevation of 13,000 feet it had changed from 80.8° to 30°. But still the conclusion that the air of the higher strata is drier than that of the lower, we are inclined to consider as fallacious. In fact the indications of the hygroscope depend on the relative attraction for humidity possessed by the substance employed, and the medium in which it is immersed. But air has its disposition to retain moisture always augmented by rarefaction, and consequently such alteration alone must materially affect the hygroscope. The only accurate instrument for ascertaining the condition of the air, with respect to dryness, is founded on a property of evaporation.

The ballast being now almost quite expended, it was resolved to descend. The aëronauts, therefore, pulled the upper valve and allowed part of the hydrogen to escape. They dropped gradually, and when they came to the height of 4,000 feet they met the stratum of clouds extending horizontally, but with a surface heaved into gentle swells. When they reached the ground, no people were near them to stop the balloon, which dragged the car to some distance along the fields. From this awkward and even dangerous situation they could not extricate themselves without discharging the whole of their gas, and therefore giving up the plan of sending M. Gay-Lussac alone to explore the highest regions. It has been reported that his companion, M. Biot, though a man of activity, and not deficient in personal courage, was so much overpowered by the alarms of their descent, as to lose for the time the entire possession of himself. The place where they alighted, at half-past one o'clock, after three hours and a half spent in the midst of the atmosphere, was near the village of Meriville, in the department of the Loiret, and about fifty miles from Paris.

It was the desire of several philosophers at Paris that M. Gay-Lussac should mount a second time, and repeat the different observations at the greatest elevation he could attain. Experience had instructed him to reduce his apparatus, and to adapt it better to the actual circumstances. As he could only count the vibrations of the magnetic needle during the very short intervals which occurred between the contrary rotations of the balloon, he preferred one of not more than six inches in length, which, therefore, oscillated quicker. The dipping needle had been magnetized and adjusted by M. Coulomb. To protect the thermometer from the direct action of the sun, it was enclosed within two concentric cylinders of pasteboard covered with gilt paper.

The hygrometers, which were made with four hairs, were sheltered nearly in the same way. The two glass flasks, intended to bring down air from the highest regions of the atmosphere, had been exhausted till the mercurial gauge stood at the 25th part of an inch, and their stopcocks were so perfectly fitted that after the lapse of eight days they still preserved their vacuum. These articles, with two barometers, were the principal instruments which M. Gay-Lussac took with him.

On the 15th September, at 9.40 A.M., the scientific voyager ascended from the same place as before. The barometer then stood at 30.66 inches, the thermometer at 82° Fahr., and the hygrometer at 57½. The sky was unclouded, but misty. Scarcely had the observer reached the height of 3,000 feet, than he observed spread below him, over the whole extent of the atmosphere, a thin vapour which rendered distant objects very indistinct. Having gained an altitude of 9,950 feet, he set his needle to vibrate, and found it to perform twenty oscillations in 83″, though it had taken 84″.33 to make the same number at the surface of the earth. At the height of 12,680 feet, he discovered the variations of the compass to be precisely the same as below; but with all the pains he could take, he was unable to determine with sufficient certainty the dip of the needle. M. Gay-Lussac continued to prosecute his other experiments with the same diligence, and with greater success. At the altitude of 14,480 feet he found that a key, held in the magnetic direction, repelled with its lower end, and attracted with its upper end, the north pole of the needle of a small compass. This observation was repeated, and with equal success, at the vast height of 20,150 feet; a clear proof that the magnetism of the earth exerts its influence at remote distances. He made not fewer than fifteen trials at different altitudes, with the oscillations of his finely suspended needle. It was generally allowed to vibrate twenty or thirty times. The mean result gives 4″.220 for each oscillation, while it was 4″.216 at the surface of the earth; an apparent difference so extremely small as to be fairly neglected.

During the whole of his gradual ascent, he noticed, at short intervals, the state of the barometer, the thermometer, and the hygrometer. Of these observations, amounting in all to twenty-one, he has given a tabular view. Leslie regrets that Gay-Lussac neglected to mark the times at which they were made, since the results appear to have been very considerably modified by the progress of the day. He also suggests that it would have been desirable to have compared them with a register noted every half-hour at the Observatory. From the surface of the earth to the height of 12,125 feet, the temperature of the atmosphere decreased regularly from 82° to 47.3° Fahr. But afterwards it increased again, and reached to 53.6° at the altitude of 14,000 feet; evidently owing to the influence of the warm currents of air, which, as the day advanced, rose continually from the heated ground. From that point the temperature diminished, with only slight deviations from a perfect regularity. At the height of 18,636 feet, the thermometer subsided to 32.9° on the verge of congelation; but it sunk to 14.9° at the enormous altitude of 22,912 feet above Paris, or 23,040 feet above the level of the sea, the utmost limit of the balloon's ascent.

Sir John Leslie thinks that from these observations no conclusive inference can be drawn respecting the mean gradation of cold which is maintained in the higher regions of the atmosphere; because the several strata are during the day kept considerably above their permanent temperature by the hot currents raised from the surface through the action of the sun's rays. Leslie had calculated that the diminution of temperature corresponding to the first part of the ascent, or 12,125 feet, ought have been 40°; but the temperature actually observed was 34.7°. In the next portion of the voyage, from the altitude of 14,000 feet to that of 18,636 feet, or the breadth of 4,636 feet, the decrease of temperature was calculated at 16¼°, whereas it was 20.7°, a proof that the diurnal heat from below had not yet produced its full effect at such a great height. In the last portion of the balloon's ascent, from 18,636 feet to 22,912, a range of 3,276 feet, the decrease of heat was calculated at 15½°, and it was actually 18°, owing most probably to the same cause, or the feebler influence which warm currents of air from the surface exert at those vast elevations. Taking the entire range of the ascent, or 22,912 feet, the diminution of temperature according to Leslie's formula would be, for the gradation of temperature in ascending the atmosphere, 85.4°. The decrease actually observed would be 67.1°, which might be raised to 80° if we admit the very probable supposition, that the surface of the earth had become heated from 82° to 94.9°, during the interval between ten o'clock in the morning, and near three in the afternoon, when the balloon floated at its greatest elevation.

It appears then from these results, that the gradation of temperature in the atmosphere is not uniform, but proceeds with augmented rapidity in the more elevated regions.

The hygrometers during the ascent of the balloon held a progress not quite so regular, but tending obviously towards dryness. At the height of 9,950 feet they had changed from 57.5°, to 62°, from which point they continued afterwards to decline, till they came to mark 27.5°, at the altitude of 15,190 feet. From this inferior limit the hygrometers advanced again, yet with some fluctuations to 35.1°, which they indicated at the height of 18,460 feet. Above this altitude the variation was slight, though rather inclining to humidity. There can exist no doubt, however, that allowing for the influence of the prevailing cold, the higher strata of the atmosphere must be generally drier than the lower, or capable of retaining, at the same temperature, a larger share of moisture.

At the altitude of 21,460 feet, M. Gay-Lussac opened one of his exhausted flasks; and at that of 21,790 feet, the other. The air rushed into them through the narrow aperture with a whistling noise. He still rose a little higher, but at eleven minutes past three o'clock, he had attained the utmost limit of his ascent, and was then 22,912 feet above Paris, being more than four miles and a quarter above the level of the sea. The air was now more than twice as thin as ordinary, the barometer having sunk to 12.95 inches. From that stupendous altitude.

1,600 feet above the level of the Andes, more elevated than the loftiest pinnacle of our globe, and far above the heights to which any mortal had ever soared, the aërial navigator calmly pursued his observations. During his former ascent, he saw the fleecy clouds spread out below him, while the canopy of heaven seemed of the deepest azure, more intense than Prussian blue. This time, however, he perceived no clouds gathered near the surface, but remarked a range of them stretching at a very considerable height over his head; the atmosphere, too, wanted transparency, and had a dull, misty appearance. The different aspect of the sky was probably owing to the direction of the wind, which blew from the north-north west, in his first voyage, but in his second from the south-east.

While occupied with experiments at this enormous elevation, he began, though warmly clad, to suffer from excessive cold, and his hands, by continued exposure, grew benumbed. He felt, likewise, a difficulty of breathing, and his pulse and respiration were much quickened. His throat became so parched from inhaling the dry attenuated air, that he could hardly swallow a morsel of bread; but he experienced no other direct inconvenience from his situation. He had indeed been affected through the whole of the day with a slight headache, brought on by the preceding fatigues and want of sleep; but though it continued without abatement, it was not increased by his ascent.

The balloon was now completely distended, and not more than [illegible] lbs. of ballast remained, it began to droop, and M. Gay-Lussac, therefore, only sought to regulate its descent. It subsided very gently, at the rate of about a mile in 8 minutes; and after the lapse of 34 minutes, or at three-quarters past 3 o'clock, the anchor touched the ground, and instantly secured the car. The voyager alighted with great ease near the hamlet of St. Gourgon, about 16 miles north-west from Rouen. The inhabitants flocked around him, offering him assistance, and eager to gratify their curiosity.

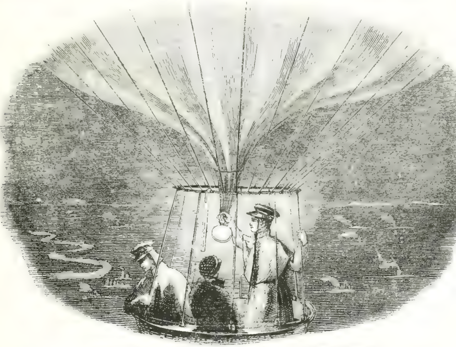

Fig. 12. THE [illegible] — See p. 19

As soon as he reached Paris, he hastened to the laboratory of the Polytechnic School with his flasks containing air of the higher regions, and proceeded to analyse it in the presence of Thenard and Gresset. Opened under water the liquid rushed into them, and apparently half filled their capacity. The transported air was found, by a very delicate analysis, to contain exactly the same proportions as that collected near the surface of the earth, every 1,000 parts holding 215 of oxygen. From concurring observations, therefore, it may be concluded that the proportions of oxygen and nitrogen in the atmosphere are essentially the same in all situations.

Sir John Leslie remarks truly, that the ascents performed by MM. Biot and Gay-Lussac are memorable, for being the first ever undertaken solely for objects of science. It is impossible, he says, not to admire the intrepid coolness with which they conducted these experiments, operating while they floated in the highest regions of the atmosphere, with the same composure and precision as if they had been quietly seated in their cabinets at Paris. Since that time numerous ascents have been performed in different countries, generally by adventurers guided by no philosophical views, nor leading to any valuable results. We may, however, remark that in 1808, Carlo Brioschi, astronomer royal at Naples, made a balloon ascent in company with Andreani, the first Italian aeronaut. In attempting to rise to a greater height than Gay-Lussac had done, they got into an atmosphere so rare that the balloon burst from the great expansion of the gas. Its shreds served to check the velocity of their descent, and falling into an open space their lives were saved, but Brioschi contracted a disease which afflicted him till his death in 1833.

We must also notice the voyage performed by Messrs. Holland, Mason, and Green, in the year 1836, as being the longest on record, the distance of about 500 miles having been performed in 18 hours. The balloon was one which had been built by the proprietors of Vauxhall Gardens. It was pear-shaped, and when inflated was 60 feet high, and about 50 feet in its largest diameter. It required 85,000 cubic feet of gas fully to distend it, and its ascensive force was about 3,000 lbs. after allowing for the weight of the machine itself and its accessories, which were estimated at 1,000lbs. The car was of wicker-work, oval in shape, 9 feet by 4 feet. The aëronauts proposed to embark in this balloon, and to proceed on whatever course the winds might direct. They do not state how long they intended to remain in the air, but they took a fortnight's provisions, laid in a ton of ballast in bags, registered and marked, while all round the hoop, and in and about the car, were suspended cloaks, carpet bags, barrels of wood and of copper to provide for their safety in case the balloon should descend into the sea, speaking trumpets, barometers telescopes, lamps, wine jars, spirit flasks, and other articles. They also had a machine for warming coffee and other liquids by means of the heat developed in the process of slaking lime. This was intended to supersede the necessity of making a fire. They had, however, a lamp, the flame of which was properly protected, to be burnt at night.

In addition to the ballast, the balloon was also furnished with a *guide-rope* about 1,000 feet long, to be lowered from the car by means of a windlass, and passing through a pulley attached to the hoop above, thus to remain freely suspended in the air. The use of this guide-rope is thus stated:—As soon as any alteration takes place, whereby the specific gravity of the balloon is increased, causing it to descend, the lower portion of this rope becomes gradually deposited on the ground, and acting like a discharge of ballast keeps constantly abstracting from her weight until her further descent is eventually checked, and she either continues to advance at the level at which she is thus reduced, or should her buoyancy from any cause be increased, she slowly rises and takes up the additional weight of rope which had been deposited on the ground. Another advantage of the guide-rope is, that in sailing by night the rope in trailing on the ground would give information to the aëronauts when the balloon was near the surface, and thus enable them to adjust the balloon to the required elevation by throwing out small portions of ballast.

Everything being got ready by 1.30 P.M. on the 7th November, 1836, the balloon rose slowly, and under the influence of a moderate breeze was borne away towards the south-east. At 2.48 they crossed the Medway, and at 4.15 saw the sea under the last rays of the setting sun. The cold caused the balloon to contract, and they descended into a current which bore them northward. As one of the objects of the expedition was if possible to get to Paris, they threw out ballast, and thus gained a higher level. In a few minutes they came over Dover, and at 4.48 quitted the shores of England, and in an hour were hovering over the French coast. As night advanced the scene was very striking. "The whole plane of the earth's surface for many a league around, as far and farther than the eye could distinctly embrace, seemed absolutely teeming with the scattered fires of a watchful population, and exhibited a starry spectacle below, that almost rivalled in brilliancy the remoter lustre of the concave firmament above. Incessantly during the earlier portion of the night, ere the inhabitants had retired to rest, large sources of light, signifying the presence of some more extensive community, would appear just looming above the distant horizon in the direction in which we were advancing, bearing at first no faint resemblance to the effect produced by some vast conflagration, when seen from such a distance as to preclude the minute investigation of its details. By degrees, as we drew nigh, this confused mass of illumination would appear to increase in intensity, extending itself over a larger portion of the earth, and assuming a more distinct form, and a more imposing appearance, until at length, having attained a position from whence we could more immediately direct our view, it would gradually resolve itself into its parts, and shooting out into streets, or spreading into squares, present us with the most perfect model of a town, diminished only in size, according to the elevation from which we happened at the time to observe it." In the course of the night, one of these scenes was particularly striking. "Situated in the centre of a district which actually appeared to blaze with the innumerable fires wherewith it was studded in every direction, to the full extent of all our visible horizon, it seemed to offer in itself, and at one glance, an epitome of all those objects which we had previously been observing in detail. The perfect correctness with which every line of street was marked out by its particular line of fires; the forms and positions of the more important features of the city, the theatres, and squares, the markets, and public buildings, indicated by the presence of the larger and more irregular accumulation of lights, added to the faint murmur of a busy population still actively engaged in the pursuits of pleasure or business, altogether combined to form a picture, which for singularity and effect certainly could never have been conceived. This was the city of Liége, remarkable for the extensive iron work which, abounding in its neighbourhood, occasioned the peculiar appearance." (Fig. 12, page 17.) After leaving this fiery district the darkness gradually increased in intensity; it seemed to the aëronauts as if they were cleaving their way through an interminable mass of black marble in which they were imbedded, and which, solid a few inches before them, seemed to soften as they approached in order to admit them still farther within its cold and dusky enclosure. In this way they proceeded blindly, as it may well be called, until about 3.30 A.M. when in the midst of impenetrable darkness and profound stillness, an unusual explosion issued from the machine above, followed by a violent rustling of the silk, and all the signs which might be supposed to accompany the bursting of the balloon. The car was violently shaken; a second and a third explosion followed in quick succession; the danger seemed immediate, when suddenly the balloon recovered her usual form and stillness. These alarming symptoms seem to have been produced by the collapsing of the balloon under the diminished temperature of the upper regions after sunset, and the silk forming into folds under the netting. Now, when the guide-rope informed the voyagers that the balloon was too near the earth, ballast was thrown out, and the balloon rising rapidly into a thinner air experienced a diminution of pressure, so that its gaseous contents would expand, and in doing so open the folds of the collapsed silk, and produce this snapping noise which had occasioned so much alarm.

The cold during the night ranged from a few degrees below, to the freezing point. As morning advanced the rushing of waters was heard, and so little were the aëronauts aware of the course which they had been pursuing during the night, that they supposed themselves to have been thrown back upon the shores of the German Ocean, or about to enter the Baltic, whereas they were actually over the Rhine, not far from Coblenz. At 5.10 A. M. they gained their greatest elevation, which was about 12,000 feet, from which objects were seen at a distance of 150 miles on every side. The view of this stupendous landscape was enjoyed for about an hour, and at 6.15 they had the satisfaction of seeing the sun rise, which still more enhanced the beauties of the scene. Shortly afterwards the balloon descended rapidly to a lower level, and all again was dark, and it was not until they had seen the sun set twice, and rise three times, that daylight was fairly established. Even then, they were not aware of their locality, and actually supposed themselves to be hovering over the "boundless plains of Poland, or the barren and inhospitable Steppes of Russia." As soon as the mist had cleared away they hastened to descend, and after many difficulties succeeded in doing so, and found themselves "in the Duchy of Nassau, about two leagues from the town of Weilburg!" This is certainly a very complete answer to those who still advocate the possibility of guiding balloons when in this, the grandest experiment in aerostation in modern times, the aëronauts were so completely at the mercy of the winds as not to know either the direction they had taken or the locality in which they had descended. Did they neglect to carry a compass with them?[1]

In this voyage all the resources of the aërostatic art were put into practice, and it will be seen how very small an advance has been made in it from the time when the first hydrogen gas balloon was launched into the air in 1783. The grandest improvement was in the use of coal-gas instead of the hydrogen, as previously obtained by a slow and costly process, an improvement which was first put in practice by Mr. Green, in his ascent from St. James's Park in 1820, at the coronation of George IV. The general introduction of coal-gas about this period, thus afforded a ready means for filling these aerial toys, which was speedily taken advantage of wherever gas-works were at hand. Coal-gas is between four and five times heavier than its own bulk of hydrogen, so that it would require about four or five times the quantity to produce the same effect; but this supposes the hydrogen to have been pure, which it never was; for not only was it loaded with moisture, but it quickly became contaminated with air; so that the balance in favour of pure hydrogen, without reference to its increased cost, cannot be very great. The specific gravity of the coal-gas of London is about 0.4, atmospheric air being 1.0; so that after allowing for the weight of the balloon, the car, the voyagers, the ballast, &c., there is still a sufficient amount of ascensional force to convey the machine and its freight into the upper regions. The ballast generally consists of bags of sand, which, on being shaken out, relieve the balloon of a portion of its load, and thereby increase the ascensional force. But as the balloon ascends, the atmospheric pressure diminishes, and causes the gas to expand, and it would in fact burst the envelope unless means were taken to allow a portion to escape. This is done by means of a safety-valve placed at the top of the balloon, and regulated by a cord passing down into the car. By this means, also, the aëronaut regulates his descent; for as the gas is allowed to escape, the weight of the machine gradually destroys the ascensional force, and the balloon descends. He still retains sufficient buoyancy to prevent the balloon from falling with a jerk, and when near the earth, a grappling-hook attached to one extremity of a rope is thrown out; when this has taken hold of the earth, the balloon is landed by drawing the rope in, and then all the remaining gas is allowed to escape.

Thus it will be seen that the only guiding power possessed by the aëronaut is that of ascent and descent within certain limits. By throwing out ballast he can ascend; by letting out gas he can descend.

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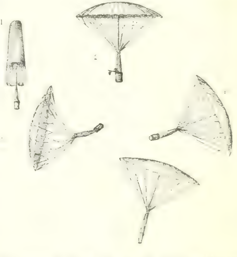
(1) The details of this voyage, and a variety of particulars and speculations respecting balloons, are given by Mr. Monck Mason, in his very amusing work entitled "Aeronautica, or Sketches Illustrative of the Theory and Practice of Aerostation." London, 1838.

He is absolutely powerless in guiding the balloon horizontally; for there is no analogy between a balloon and a ship sailing in the water. In the ship the action of the water on the rudder is a guide to the impelling force of the winds acting on the sails. No such regulator as the rudder can be applied to a balloon, because it is sustained in as well as impelled by the air. It is stated, however, by Mr. Green, and Mr. Monck Mason, from their own aëronautic experience, that "in this country, whatever may be the direction of the wind below, within 10,000 feet above the surface of the earth, the direction of the wind is invariably from some point between the north and west." If this really be the case, the aëronaut has only to ascend to the height named, and he will find an upper current always ready to convey him in any direction between south and east.

One of the chief dangers in aërial excursions arises from a rapid and premature descent. To guard, in some degree, against such an occurrence, the *parachute*, or guard for falling, was introduced. The parachute resembles a large umbrella, sufficiently strong to resist the action of a moderate wind, and sufficiently large to offer a resistance equal to the weight of the person descending in it, so that it may reach the earth with a velocity not exceeding that of the shock which a person can sustain without danger.

Blanchard was the first aëronaut who attached a parachute to a balloon. During the excursion which he undertook from Lisle, in August, 1785, when he traversed a distance of 300 miles without halting, he let down a dog from a vast height in the basket of a parachute, and the poor animal, falling gently through the air, reached the ground unhurt. Another aëronaut, M. Garnerin, even ventured on many occasions to descend from the clouds in this frail machine. During the short peace of 1802, he visited London, and made two ascents with his balloon, in the second of which he threw himself from an amazing elevation with a parachute. This consisted of 32 gores of white canvass formed into a hemispherical case of 23 feet diameter, at the top of which was a round piece of wood with a hole in its centre, admitting short pieces of tape to fasten it to the several gores of the canvass. About 4½ feet below the top, a wooden hoop 8 feet in diameter, was attached by a string from each seam, so that when the balloon rose the parachute hung like a curtain from this hoop, as in No. 1 of Fig. 13. Below was suspended a cylindrical basket covered with canvass, about 4 feet high and 2½ feet wide. In this basket the aëronaut, dressed in a close jacket, placed himself and ascended from an inclosure near North Audley Street, at 6 P.M. of the 2d September. After hovering 7 or 8 minutes in the upper region of the atmosphere, he cut the cord by which his parachute was attached to the net of the balloon. The balloon immediately ascended and was lost, but the parachute instantly expanded, as in No. 2, and for some seconds descended with an accelerating velocity, until it became tossed extremely, as in Nos. 4 and 5, and took such wild oscillations that the basket was sometimes thrown into a nearly horizontal position, as in No. 3. At the same time being carried along by the wind, the parachute passed over Marylebone and Somers Town, and almost grazed the houses of St Pancras.

Fig. 13.



At length it struck the ground in a neighbouring field, but with a shock so violent, that Garnerin was thrown on his face and injured. It appears that one of the stays of the parachute had given way and had thrown the apparatus out of its proper balance, thus threatening the aëronaut with destruction during the whole of his descent.

Mr. Monck Mason states an interesting meteorological fact as having been established by aëronautic observation. It appears that whenever a fall of rain occurs, and the sky is at the same time entirely overcast with clouds, there will be found to exist another stratum of clouds at a certain elevation above the former. So also, when the sky is entirely overcast, and rain is altogether or generally absent, the aëronaut, upon traversing the canopy immediately above him, is sure to enter upon another hemisphere, either perfectly cloudless or nearly so. Mr. M. Mason states that this fact has been verified during many hundred ascents. For example, during an ascent on the 12th October, 1837, "the sky was completely overspread with clouds, and torrents of rain fell incessantly during the whole of the day. Upon quitting the earth, the balloon was almost immediately enveloped in the clouds, through which it continued to work its way upwards for a few seconds. Upon emerging at the other side of this dense canopy, a vacant space, of some thousand feet in breadth, intervened, above which lay another stratum of a similar form and observing a similar character. As the rain, however, still continued to pour from this second layer of clouds, to preserve the correctness of the observation a third layer should by right have existed at a still further elevation; which, accordingly, proved to be the case. On the subsequent occasion of the ascent of the same balloon, (October 17th,) an exactly similar condition of the atmosphere, with respect to clouds, prevailed; unaccompanied, however, with the slightest appearance of rain. No sooner had the balloon passed the layer of clouds immediately above the surface of the earth, than, as was anticipated, not a single cloud was to be found in the firmament beyond; an unbroken expanse of clear blue sky every where embracing the frothy plain that completely intercepted all view of the world beneath."

The following particulars are abridged from Mr. Mason's work. When the balloon is held down to the earth, there are many effects which remind the aeronaut of the presence of the ocean of air into which he is about to be launched: the balloon heaves, the silk flaps and rustles, and the wind sighs through the cordage; but the moment he quits the earth not a motion is felt, not a breath of wind is perceptible, the balloon, as if arrested by some powerful and invisible agent, suddenly assumes an upright posture, and stands, as it were, fixed, rigid, and immovable; and the mind of the adventurer becomes impressed with the idea of an universal and unnatural calm. This state of things continues so long as the balloon is left free to pursue her own course upon the same level. Totally independent of the rate or direction of the current, the idea of absolute quiet remains the same, whether the actual progress of the balloon be 1 or 100 miles an hour, whether it be in one continued line, or subject to the most rapid and incessant variation. The greatest storm that ever racked the face of nature is, in respect to its influence upon this condition of the balloon, as utterly powerless as the most unruffled calm. To such an extent is this the case, so truly indeed is atmospheric resistance a nullity to the aëronaut, that were we to suppose him (by way of illustration) suddenly transported to the West Indies, the birthplace and habitation of the tornado and the hurricane, traversing the skies at a time when one of the wildest and fiercest was executing its utmost powers of devastation, looking down from his airborne car, and beholding houses levelled, trees uprooted, rocks translated from their stony bed and hurled into the sea, earth and ocean in mutual aggression, encroaching upon each other's limits, and all the various signs of desolation by which its path is marked, he might nevertheless hold in his hand a lighted taper without extinguishing the flame, or even indicating by its inclination to one side or the other, the direction of the mighty agent by which such awful ravages had been created. [See Appendix.]

AFFINITY. Chemical affinity or attraction, is that particular power or force by which dissimilar bodies become combined in intimate relationship,[1] (Latin *affinis*, a kinsman,) forming a new substance, whose properties are, for the most part, entirely different from those of its component parts. If two bodies be simply mixed together, the properties of the mixture form a *mean* between those of its components; but if two bodies combine chemically, we get different properties. In the mixture we may still recognise the distinctive properties of the two bodies brought together; in the chemical compound we have the properties of a third substance. For example, a mixture of magnesia and water produces almost no chemical change; the combination is almost purely mechanical; the water dissolves less than a six-thousandth part of this earth, so that by passing the mixture through a filter, the water and the magnesia can be almost perfectly separated. If, however, we add magnesia to dilute sulphuric acid, a true chemical combination takes place: 20 parts of magnesia combine with 40 of sulphuric acid and 63 of water to form 123 parts of sulphate of magnesia, a crystalline salt, soluble in its own weight of water at 60°, and of a nauseous bitter taste. In fact, we get a new compound, whose chemical properties are totally different from those of its component parts. The acid is intensely sour and caustic, the earth is insipid and slightly alkaline; combine the two and we get Epsom Salts.

To take another example; the atmospheric air is composed essentially of two gases, oxygen and nitrogen, which are mechanically mixed in the proportion of 4 volumes of nitrogen to 1 of oxygen. If these bodies be combined chemically and in different proportions, we get totally new substances; 14 parts, by weight, of nitrogen combined with 8 parts, by weight, of oxygen, produces a gas called *nitrous oxide*, which has a faint, agreeable smell; is absorbed by cold water to the extent of about three fourths of its volume; mixed with hydrogen and ignited, it explodes; combustible bodies burn in it with increased brilliancy, and when taken into the lungs it produces a sort of intoxication, generally accompanied by convulsions of laughter. 14 parts of nitrogen with 16 of oxygen produce a gas, the *nitric oxide*, which has totally different chemical properties. Cold water scarcely absorbs it; mixed with hydrogen it burns with a green flame; a lighted taper will not burn in it; any attempt to breathe it produces suffocation, and when let out into the air it forms a vapour of a reddish brown colour. 14 parts of nitrogen combined with 40 of oxygen form nitric acid, a corrosive poison, and one of the most powerful of the mineral acids.

But it is not always easy to mark the limit between mechanical mixture and chemical combination. When a body dissolves in a liquid, there is a weak kind of affinity between the substance dissolved and the solvent, as when salt is dissolved in water; but this can scarcely be called a case of affinity, for by evaporating the solution the salt can be recovered unchanged, which cannot be done when bodies combine chemically.

Chemical affinity, as already stated, applies only to the union of dissimilar bodies. There are some bodies, such as oil and water, water and mercury, which refuse to unite, and in such case it is said that there is no affinity between such bodies. This is not telling us much, for as the real nature of affinity is not known, we only disguise our ignorance by stating

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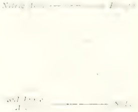
(1) The term affinity was first employed by Boerhaave in a figurative sense, to indicate certain peculiar attachments and attractions between different bodies.

that oil and water will not unite because these bodies have no affinity for each other.

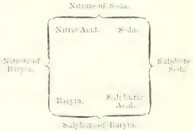
Chemists distinguish various kinds of affinity. *Single affinity* is that in which two bodies unite to form a binary compound. These may be two simple substances, as when oxygen and iron unite to form oxide of iron, or sulphur and copper to form sulphuret of copper; or two compounds may unite, as sulphuric acid and oxide of iron, to form sulphate of iron. But a simple substance does not often unite with a compound one; thus sulphuric acid does not unite with iron, nor does sulphur unite with oxide of copper. If we oxidise the iron, the acid unites with it readily; and if we deoxidise the copper, the sulphur will unite with it. There are, however, exceptions to this rule.

Affinity is also spoken of as being *elective*. Thus if dilute nitric acid be poured upon a mixture of lime and magnesia, the acid will unite with the lime in preference to the magnesia. Hence it is said, that nitric acid has a greater affinity for lime than for magnesia, and the fact may be shown in another way. If lime water be added to a solution of nitrate of magnesia, nitrate of lime is formed and magnesia is thrown down as an insoluble precipitate. This is a case of *single elective affinity*. There is another mode by which compounds are formed, namely, by *double decomposition* or *double elective affinity*. This is very useful in obtaining compounds which could not otherwise be procured, in many cases, without great difficulty. For example, nitrate of baryta and sulphate of soda are salts soluble in water. If the solutions of these salts be mingled together, two new compounds are formed, one of which is soluble and the other not. The change that takes place will be understood from the following diagram, in which the



substances before being mixed are shown in the parallel lines, and after mixture in the diagonal lines. The nitric acid quits the baryta to unite with the soda, forming nitrate of soda, which remains in solution; and the sulphuric acid quits the soda to unite with the baryta, forming sulphate of baryta, which is an insoluble precipitate. Some of the processes of the dyer depend upon such a case as this, which may be still more completely illustrated by the following diagram, where the solutions before being mixed are placed on the outside of the perpendicular lines, their component parts are shown within them, and the new compounds are stated on the outside of the horizontal lines.

It was formerly supposed that the relations of affinity were fixed and constant between the same substances, and the older chemists took great pains to prepare tables of what was called the *precedence of affinities*.



The following is an example of one of these tables, which illustrates the relative affinities of a number of bases for sulphuric acid, each decomposing the combination of the acid with the base below it. Thus magnesia decomposes sulphate of ammonia; lime displaces the acid from sulphate of magnesia, &c. The salts are supposed to be dissolved in water.

SULPHURIC ACID.

Baryta
Strontia
Potash.
Soda.
Lime.
Magnesia.
Ammonia.

Professor Fownes remarks, that "the order pointed out in these lists, is now acknowledged to represent the order of precedence *for the circumstances* under which the experiments were made, but nothing more. So soon as these circumstances become changed, the order is disturbed. The ultimate effect, indeed, is not the result of the exercise of one single force, but rather the joint effect of a number, so complicated and so variable in intensity, that it is seldom possible to predict the consequences of any yet untried experiment."[1]

There is an extensive class of chemical actions which have been grouped together under the general title of *disposing* affinity. A familiar example of this occurs in the preparation of hydrogen gas from zinc or iron and dilute sulphuric acid. A piece of polished zinc or iron remains perfectly bright under water for any length of time, and does not show any tendency to decompose it. But if a small quantity of sulphuric acid be added, the water begins to be decomposed, hydrogen is freely evolved, a film of oxide forms on the metal, and this is dissolved by the acid as fast as it is formed. This appears to be the use of the acid in this experiment, but it is difficult to explain why the oxide should be produced when the acid is present and not otherwise.

Chemical affinity is promoted by many circumstances, especially by diminishing the cohesive attraction of the bodies to be acted on. Thus a lump of marble in dilute hydrochloric acid slowly wastes away, but by reducing the marble to powder, the action is very rapid and energetic. A lump of antimony thrown into chlorine gas is scarcely acted on, but the metal in the state of powder immediately combines with the gas, with the evolution of heat and light, and a chloride of antimony is at once formed. Masses of iron, copper, and lead, resist the action of the atmosphere; they become slightly tarnished with oxides which protect them from further action; but in a state of minute division they are acted upon with great energy, and often present the phenomena of combustion by simple exposure to the air. It is also often necessary for the exhibition of chemical affinity, that one of the bodies should be in a fluid state. Solutions mostly depend on this condition; and here again a state of minute division is important, merely by increasing the surface of contact between the solvent and the body to be dissolved, thus offering an immense number of points where the action may simultaneously be exerted.

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[1] Fownes' Manual of Chemistry, [illegible]

Many bodies will only combine in what is called the *nascent state*, or at the moment of separation from combination. Thus carbon and nitrogen will not combine with gaseous hydrogen; but when these bodies are simultaneously liberated from some previous combination they unite readily, as when organic matters are destroyed by heat or by putrefactive fermentation.

Affinity is in most cases greatly promoted by heat. Melted sulphur will not combine with carbon, but by raising the sulphur to the state of vapour, and bringing it in contact with red-hot charcoal, these bodies combine and form sulphuret of carbon, a limpid, colourless liquid. Charcoal requires to be made red-hot before it will burn in oxygen gas, that is, before it will combine with oxygen. At ordinary temperatures, oxygen may be mixed with hydrogen and other inflammable gases without combining with them, but on the approach of flame or the electric spark, combination takes place immediately. Cold water dissolves many salts only to a limited extent, but the application of heat greatly increases the solvent power of the water. There are, however, some salts which dissolve more freely in cold than in hot water, but these form exceptions to the general rule. Heat also favours decomposition as well as affinity. For example, if mercury be heated in contact with the atmosphere, it is converted into a peroxide by combining with the oxygen of the air; now if this compound be again heated to a higher temperature than was required for its formation, it is decomposed; oxygen is given off, and the mercury returns to the metallic state. So also, if iron filings be heated to redness in a porcelain tube, and vapour of water be passed over them, the water is decomposed, its oxygen combining with the iron to form an oxide, and its hydrogen escaping from the extremity of the tube. If, on the contrary, oxide of iron be heated in a tube and a stream of dry hydrogen be passed over it, the metal is immediately reduced by the hydrogen uniting with the oxygen of the oxide, and forming water, which escapes as a jet of steam from the extremity of the tube. "In these experiments," says Fownes, "the affinities between the iron and oxygen and the hydrogen and oxygen are so nearly balanced, that the difference of *atmosphere* is sufficient to settle the point. An atmosphere of steam offers little resistance to the escape of hydrogen; one of hydrogen bears the same relation to steam; and this apparently trifling difference of circumstances is quite enough for the purpose."

Electricity has considerable influence over chemical affinity. A mixture of oxygen and hydrogen instantly combines by passing an electric spark through it, but this is probably a mere effect of heat. By passing a series of electric sparks through a mixture of oxygen and nitrogen, nitric acid is formed. A portion of this acid also appears to be formed in the atmosphere during a thunder storm, and the action of electricity in these cases is probably more specific than that of heat. But of all the various states of electricity, galvanism is the most interesting in a chemical point of view. By means of the voltaic pile or battery, a large number of chemical compounds have been decomposed. When, for example, two platina wires are connected with the poles or electrodes of a voltaic battery, and their unconnected ends are immersed in water, oxygen gas is evolved at the positive pole, or, as it is now called, the *anode*,[1] and hydrogen gas is evolved at the negative pole or *cathode*.[2] So, also, when saline solutions are submitted to the action of the battery, acids are developed at the anode, and alkaline bases at the cathode.

Now it is a law of electricity, that bodies dissimilarly electrified attract each other; and as in these decompositions oxygen, chlorine, acids, &c. invariably go over to the positive pole, and hydrogen, the metals, inflammable substances in general, and the alkalies, appear at the negative pole, it has been supposed that chemical affinity, or that force with which bodies combine, is a consequence of their being in opposite electrical states; that an acid being negative, and an alkali being positive, unite to form a salt, and that when the union is once effected, the electricity of the compound exists in a neutral state, or in a state of equilibrium. When, however, the superior force of the voltaic battery is brought to bear upon such a compound, its constituents separate and return to the natural electric state which they had before combination. Hence it has been supposed, that when substances or their atoms are similarly electrified, they refuse to combine, but that they may be made to do so by communicating to them opposite electrical states. This theory has been useful to chemistry, but it is by no means certain that chemical affinity is identical with electrical attraction. According to Dr. Faraday, chemical affinity is merely a result of the electrical state of the particles of matter. He has found that when bodies are combined or decomposed by an electric current, the composition and the decomposition are always effected according to the laws of definite proportions; and that the quantity of electricity requisite for the decomposition of a substance, is exactly the quantity necessary for its composition. Thus the quantity of electricity which can decompose a grain of water is exactly equal to the quantity of electricity which unites the elements of that grain of water together. [ATOMIC THEORY.]

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[1] The surface at which the electric current enters the electrolyte.

[2] The surface at which the electric current leaves the body under decomposition.

Light has also considerable influence in controlling chemical affinity. Hydrogen and chlorine gases mixed and exposed to the sun's rays combine with explosion, and form hydrochloric acid. Chlorine and carbonic oxide gases exert no action on each other until they are exposed to the light, when they combine and form phosgene gas. The beautiful chemical arts of PHOTOGRAPHY and DAGUERREOTYPE depend upon the action of light upon chemical substances.

AGATE, from ἀχάτης, a stone, said by Theophrastus to come from the river Achates, in Sicily, now called the Drillo, in the Val di Noto. It is one of the numerous forms in which silica is arranged, and contains 98 per cent. of that mineral. It is not transparent, like rock-crystal, but almost opaque, with a resinous or waxy fracture, and with various shades of colour produced by the presence of minute portions of iron. When agates are cut open they display a singular variety of forms, in some cases resembling animals and plants, in others zigzag lines like the plan of a modern fortification, and hence this variety is called *Fortification Agate*. These lines are the edges of successive layers or deposits of the mineral during the process of its formation. As the internal surfaces are capable of receiving a high degree of polish, agates are much valued as ornamental stones. They are extensively used at Paris and elsewhere, in the manufacture of cups, rings, seals, handles for knives and forks, sword-hilts, beads, smelling-bottles, snuff-boxes, and other articles. Burnishers are also formed of agate, for the use of the bookbinder and other mechanics. Agates are usually met with in that variety of trap-rocks called

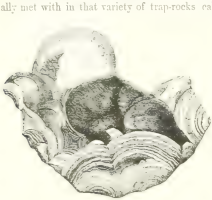


Fig. 14.—Agate.

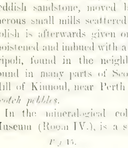
am[illegible] rounded nodules, not cemented to the rock, but easily separable from it, having generally a thin layer of green earth interposed, and a rough, irregular exterior. Agates are also met with as loose pebbles in the beds of rivers or in gravel, and they vary in size, from that of a millet seed to a foot in diameter; but the most common size is 1, 2, or 3 inches in diameter. The colours of agate may be darkened by boiling the stone in oil, and then dropping it into sulphuric acid. A little oil is absorbed by some of the layers, and this becomes blackened or charred by the acid. Fig. 14 is a copy of a good specimen of an agate with chalcedony.

There are various other siliceous stones closely allied to agate, and not to be distinguished from it in chemical composition, except as respects the colouring matter of one or two of them. These are, 1. *Carnelian*, so called from the Latin *carnis*, flesh, some of the most common varieties being of a flesh colour. There are, however, various shades of red and yellow, but the deep, clear red is the rarest, and most valuable. The colours may be deepened by exposing the stones for several weeks to the sun's rays. The chief supply of carnelians is from Japan; they are also imported from Bombay, after being collected in the province of Guzzerat; but the best varieties are said to come from the gulf of Cambay. Many antique gems are in carnelian, and the stone is now much used for seals and beads. The Japanese cut beads of it into the form of the fruit of the olive. 2. *Calcedony*, so called from its being found at Chalcedon, in Bithynia, opposite to Constantinople. This is a gem of a uniform milky white, or pale yellow colour: it often has a wavy structure, and a peculiar blistered surface. It is found abundantly in the Faroe Islands, in Iceland, Cornwall, and many other places. It sometimes occurs in large masses, of which cups and vessels are formed. 3. *Onyx*. In this variety of agate, the siliceous particles are arranged in alternate flat layers, of an opaque white and translucent grey or brown colour, resembling the marks on the human nail, whence its name from the Greek word ὄνυξ, a nail. Some of the most beautiful of the ancient cameos were executed in this material, the figure being cut out of the opaque white, while the dark parts formed the ground; or the white parts formed the ground, and the dark parts the figure. 4. *Sardonyx*, a variety of onyx from *Sardes*, in Lydia, or, as some say, from *Sardo*, the Greek name for Sardinia. In this stone, the opaque white alternates with a rich, deep orange brown, which, when considerably translucent, greatly adds to its value. 5. *Mocha stones* and *moss agates* are transparent varieties of calcedony, the section of which exhibits various forms produced by iron, manganese, bitumen, and chlorite or green earth, but sometimes, also, by the presence of real vegetable bodies, such as confervæ and mosses. Mocha stones are so called from having been brought from Mocha in Arabia. 6. *Blood-stone*, a green agate coloured by chlorite with numerous bright red spots like drops of blood. It is also called *Heliotrope*, and *Oriental Jasper*. 7. *Chrysoprase*, from χρύσεος, beautiful, and πράσον, a leek; a variety of calcedony found in Silesia; its colour, which is of an apple-green, is due to oxide of nickel. 8. *Plasma*, a green semi-transparent calcedony, of a dark tint sprinkled by yellow and whitish dots. It is coloured by chlorite.

The figured agates of commerce are chiefly obtained from Oberstein, a small town in the valley of the Nahe, not far from Mayence. The business of cutting and polishing the agates, occupies a considerable number of the inhabitants. The surface is first coarsely ground by large mill-stones of a hard, reddish sandstone, moved by water-wheels, in numerous small mills scattered along the stream. The polish is afterwards given on a wheel of soft wood, moistened and imbued with a fine powder of hard red tripoli, found in the neighbourhood. Agates are found in many parts of Scotland, especially at the Hill of Kinnoul, near Perth; they are hence called *Scotch pebbles*.

In the mineralogical collection of the British Museum (Room IV.), is a specimen of Globular or Egyptian Jasper, which exhibits in the two fractural surfaces a likeness of the poet Chaucer. Fig. 15 is an accurate copy of this curious specimen. In the same case [No. 24] are other specimens of siliceous minerals, the lines of which fall into the shapes of animals, &c.

Fig. 15.



AIR, (from the Greek and Latin *aer*,) a term now limited to the atmosphere, although formerly applied to various gases; thus oxygen was called *vital air*; hydrogen, *inflammable air*; carbonic acid, *fixed air*; ammoniacal gas, *alkaline air*, &c. The atmosphere or sphere of gases (ἀτμοὶ) is the general term applied to the whole gaseous portion of this earth. Being much lighter than either land or water, it floats or rests upon them, and rises to the height of probably 40 or 50 miles above the sea-level. It consists essentially of two gases, OXYGEN and NITROGEN, in a state of mechanical mixture. One hundred parts by weight, contain 77 parts nitrogen and 23 parts oxygen; or by measure, 79.19 nitrogen, and 20.81 oxygen. So that if we mix 1 volume of oxygen with 4 volumes of nitrogen, we get a mechanical compound almost identical with pure atmospheric air. Oxygen is remarkable for its active properties: it promotes combustion, respiration, and other chemical changes, with great energy. Nitrogen, on the contrary, is inert; it supports neither respiration nor combustion, and its chief use in the atmosphere seems to be to dilute the oxygen. During the processes of respiration and combustion, a quantity of carbon is set free, every 6 parts of which, by weight, unite with 16 parts by weight of oxygen, and form a compound gas, called CARBONIC ACID, which is always present in the atmosphere in small but varying quantities. In 10,000 volumes of atmospheric air, the mean proportion of carbonic acid is only 5 volumes, and this varies from 6.2 as a maximum, to 3.7 as a minimum. Near the surface of the earth, the proportion of carbonic acid is greater in summer than in winter, and during night than during day. It is also rather more abundant in elevated situations, as on the summits of high mountains, than in the plains; and, although this gas is considerably heavier than its own bulk of pure atmospheric air, (its specific gravity being about 1.52, air being 1,) yet it appears to be diffused through the whole mass.

By the evaporation of the waters of the earth, and of moist surfaces, the atmosphere is constantly supplied with a quantity of aqueous vapour. In 100 parts by weight of atmospheric air, the mean quantity of watery vapour is nearly one part and a half. The amount, however, varies with the temperature. At 50°, the mean temperature of England, the air contains $\frac{1}{120}$th of its weight of water in an invisible state without forming cloud, mist or rain. If it contain more than this, it is precipitated in a visible form. At a higher temperature a larger quantity of vapour may remain invisible; thus, at 82°, the mean temperature of the equator, the air may contain as much as $\frac{1}{43}$d of its weight of invisible steam; and air that contained only $\frac{1}{120}$th would be injuriously dry, though the same air cooled down to 50°, would be at its maximum of humidity. [EVAPORATION.]

As the sea contains a little of everything that is soluble in water, so the atmosphere contains a little of everything capable of existing in the gaseous form at common temperatures. Ammonia is always present, and is supposed to be the source of nitrogen in plants; while in crowded cities, and in the neighbourhood of gas works, smelting furnaces, sewers, stagnant pools, sulphur-springs, &c. there is much local contamination of the air from the presence of different gases. Various forms of infection, malaria, and marsh-miasma, probably arise from the presence of noxious gases in the air. Berzelius states that in the first experiments which he made upon seleniuretted hydrogen, he let up into his nostrils a bubble about the size of a pea. "It deprived me so completely of the sense of smell, that I could apply a bottle of concentrated ammonia to my nose without perceiving any odour. After 5 or 6 hours I began to recover the sense of smell, but a severe catarrh remained for about 15 days." On another occasion a little of the gas accidentally escaped; it produced a sharp sensation in the nose, red eyes, and a dry and painful cough, which at length was succeeded by expectoration, tasting like the vapour from a boiling solution of corrosive sublimate. "These symptoms were removed by a blister to my chest. The quantity of seleniuretted hydrogen gas, which on each of these occasions entered into my organs of respiration, was much smaller than would have been required of any other inorganic substance whatever to produce similar effects." Dr. Prout quotes these facts to show how small a quantity of accidental ingredients diffused in the atmosphere may produce powerful effects in the human system, and may even be the origin of influenza, and other epidemic disorders.

With respect, however, to the two essential ingredients of the atmosphere, they always exist in the same proportions, however the air may be vitiated by carbonic acid, animal effluvia, and other accidental ingredients. Air has been brought from the summits of Mont Blanc and Chimborazo, and from the plains of Egypt; it has been collected and examined in crowded cities, and in fever hospitals; but in all cases the proportions of oxygen and nitrogen remain unaltered, the diffusive energy of the gases maintaining this perfect uniformity of mixture.

This mechanical compound the atmosphere forms, therefore, a fluid ocean at the bottom of which we live, and which envelopes everything, and exerts such a pressure upon everything, as is quite incredible to persons who approach this subject for the first time.

Although air is invisible, and is very much lighter than solid and liquid bodies, yet like them it is material, and possesses many of their physical properties, together with other properties peculiar to aëriform fluids. Air possesses impenetrability; that is, it will not allow the entrance of another body into the space where it is present. If a vessel be completely full of water, a solid plunged into it will displace a portion of the water equal to the bulk of the solid. So, also, if we plunge a solid into what is called an empty glass, it will displace a portion of the air contained in such glass equal to its own bulk. The impenetrability of air is well illustrated by plunging an inverted goblet into a vessel of water, keeping the edge horizontal, and it will be found that to whatever depth we plunge it, the water will not entirely fill it. The air will be compressed into a smaller space, but will not be displaced. A diving bell at a depth of 34 feet below the surface of the water, will be half filled with water; at 100 feet it will be three-quarters filled; at 1,000 feet it will be filled to within a thirtieth; but on drawing it up to the surface the air will expand to its original bulk, and drive out all the water.

Air being material also possesses *weight;* that is, it obeys the attractive influence of the earth, and gravitates towards its centre. This may be proved by suspending a copper flask, of the capacity of 100 cubic inches, to one extremity of the arm of a delicate balance, and accurately counterpoising it with weights in the opposite scale. If the air be pumped out of the flask it will be found to have lost weight: it will have lost about 31 grains; but on readmitting the air the flask will weigh as much as before. It has been found by accurate experiments, that 100 cubic inches of pure and dry air, weigh 31.0117 grains, at the temperature of 60°, and under a pressure of 30 inches.

Air, then, is a ponderable substance, and, in common with all such, has *inertia*, that is, it cannot be set in motion without the communication of some force, and when in motion, it cannot be retarded or brought to rest without the opposition of force. Its inertia, like that of all other bodies, is exactly proportional to its weight; and as this is small compared with its bulk, a small force is sufficient to impart motion to a large bulk of air. It obeys the laws of motion common to ponderable bodies, and its *momentum*, or amount of force which it is capable of exerting upon bodies opposed to it, is estimated in the same way as for solids, viz. by multiplying its weight by its velocity. The momentum of air is usefully employed as a mechanical force in imparting motion to windmills and ships.

Another consequence of the weight of air is its *pressure.* We have seen that 100 cubic inches of air weigh about 31 grains. This however is only at or near the level of the sea, with the barometer standing at 30 inches; for if this 100 inches of air be taken up in a balloon, to the height of 14,282 feet, or 2.705 miles, the 100 cubic inches will expand to 200, because, at that elevation, we have ascended above half the atmosphere, and the 100 cubic inches of air has to bear only half the pressure to which it was subjected at the level of the sea. Now it is a law peculiar to gaseous matter, that its density is proportional to the pressure that confines it; that is to say, by doubling this pressure we compress any air or gas into half its former bulk; and on the contrary, by removing half the pressure from any air or gas, it expands to twice its ordinary bulk; so that there does not appear to be any limit to the space which any quantity of air, however small, would fill if relieved of all pressure. Thus, the zone or shell of air which surrounds the earth, to the height of nearly 2¾ miles from its surface, contains one half of the atmosphere; and the remaining half being relieved of this superincumbent pressure, expands into another zone or belt, of the thickness of 41 or 42 miles.

The pressure of the air at the sea level, will be further examined when we come to notice the BAROMETER; but its amount may be shown by the Magdeburg hemispheres, fig. 16, which consist of 2 hollow hemispheres of brass, which fit together with smooth edges. The lower hemisphere is furnished with a short tube opening into it, which can be opened or closed by means of a stop-cock. On screwing this tube into the table of an air-pump and placing the two hemispheres together, the air can be withdrawn from the hollow sphere thus formed, and on turning the stop-cock and removing the apparatus the air cannot re-enter. A handle may be screwed to the short tube, and if two persons pull in opposite directions they will be unable to separate the hemispheres. If the sphere be 6 inches in diameter, its section through the centre will be about 29 square inches, and supposing the vacuum to be perfect, a weight of 420lbs. will be required to separate the hemispheres.[1]

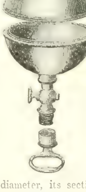


Fig. 16.

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[1] This experiment derives its name from Magdeburg, the place where it was first tried by Otto Guericke, a wealthy magistrate, who, in the year 1654, had the honour of exhibiting it on a large scale, before the princes of the empire and the foreign

Now $\frac{432}{30}$ = about $14\frac{1}{2}$ lbs. which is the amount of atmospheric pressure upon 1 square inch of surface.

To this pressure all bodies animate and inanimate, situated at or near the level of the sea, are subject. By calculating the number of square inches on the surface of the body of a man of ordinary stature, and multiplying this number by $14\frac{1}{2}$, we get the number of pounds pressure to which his body is subject from the atmosphere: this will be found to amount to no less than 33,600 lbs., or about 15 tons. Why then is he not crushed beneath so enormous a load? is a very natural inquiry. To this it may be answered, that at the bottom of the ocean of water, many frail and delicate animals live and enjoy life, and move about with perfect freedom, just as we do at the bottom of our ocean of air; and yet these creatures are subject to a pressure of from 60 to 90 times greater than we sustain. They are not crushed because the hydrostatic pressure is equal on all sides: the bodies of these animals are equally pressed above, below, and around, and the fluids within the animal are also either of similar density or they are nearly incompressible. So, also, our atmosphere presses equally in all directions, and our bodies are filled with liquids capable of sustaining pressure, or with air of the same density as the external air, so that the external pressure is met and counteracted by the internal resistance. Fishes which live at great depths in the sea, are as effectually destroyed when drawn up to the surface and the hydrostatic pressure removed, as we should be if taken to a great height in the atmosphere, where the pneumatic pressure would be removed or nearly so. We become painfully sensible of atmospheric pressure in the operation of cupping, and also in the experiment with the hand-glass, fig. 17,

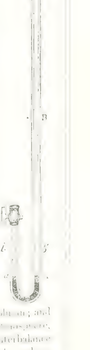
Fig. **17.**

which is a stout glass open at both ends if the broader end be placed on the table of the air-pump and the upper end be closed with the palm of the hand, the removal of a portion of air from the interior of the glass will cause an intolerable load to be felt on the back of the hand: this is the atmospheric pressure now unbalanced, because it does not press below as well as above the hand.

It has been stated that when a given volume of air is released from pressure it will expand to an indefinite extent, and that when the same amount of pressure is restored it will regain its former bulk. This property of *elasticity* is one of the most striking features of aeriform matter, and is a consequence of its peculiar structure. The atoms or particles of solids are held together by an attractive force called *cohesion*, which differs in different solids, as is evident from the various degrees of force required to overcome it, as in breaking them, or crushing and grinding them to powder. In liquids, the cohesive attraction is so weak that the particles glide over each other and instantly mould themselves to the form of the vessel or channel necessary to contain them. In air, gases, and vapours, cohesive attraction is altogether absent; the particles not only do not cohere, but repel each other with so powerful a force, that they constantly tend to separate themselves from each other, so as to occupy a larger space. It is this repulsive force which constitutes the elasticity of gaseous bodies.

This property of air, and the law by which it is governed, can be illustrated by means of a long bent glass tube, open at its longer extremity, and furnished with a stop-cock at the shorter. The stop-cock being open, a quantity of mercury is poured into the open end, and the surfaces of the mercury A *a* will of course stand at the same level in both limbs of the tube. The two columns of air, A C and *a* D, sustain a pressure equal to the weight of a column of air continued from A and *a* to the top of the atmosphere. If we now close the stop-cock D, the effect of the whole weight of the atmosphere above that point is cut off, so that the surface *a* can sustain no pressure from the weight of the atmosphere. The level of the mercury, however, remains the same, because the elasticity of the column of air *a* D, is equal to the weight of the whole column before this small length was cut off. Under this condition of the experiment, it may be said that the surface A is pressed by the *weight* of the whole atmospheric column, and the surface *a*, by the *elasticity* of a portion of air which has been subjected to the weight of the whole atmospheric column; and that these two different properties of the atmosphere, its weight and its elasticity, exactly counterbalance each other; because the pressure of the atmosphere on A is transmitted to the surface *a*, and the elasticity of the confined portion of air on *a* is transmitted to the surface A, thus producing equilibrium.

Fig. 18.



We have seen that the pressure of the air is equal to about $14\frac{1}{2}$ lbs. on the square inch. This pressure will sustain a column of mercury 30 inches high and an inch square; or in other words, the weight of such a column of mercury is equal to about $14\frac{1}{2}$ lbs. Now if we pour an additional quantity of mercury into the long limb, so as to compress the air in *a* D into half its former limits, that is, until the surface of the mercury rise from *a* to *b*, and then draw a horizontal line from *b* to the opposite point *b'* in the longer limb, it will be found that the column of mercury *b'* B required to compress the air in *a* D to half its former limits, measures exactly 30 inches, the weight of which is equal to the atmospheric pressure. The force with which the surface *b* is pressed upwards towards D is therefore equal to *two atmospheres*, or double the force with which *a* was pressed upwards towards D. Consequently the elasticity of the confined column *b* D, is double its former elasticity or that which it had when filling the space

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ministers, assembled at the diet of Ratisbon. The force of two teams, each consisting of a dozen horses made to pull in opposite directions, was found insufficient to separate the [illegible] plates

: D, so that when air is compressed into half its volume its elasticity is doubled. On again pouring mercury into the tube at C until the air in the shorter limb is reduced to a third of its bulk as at c D, the compressing force will be equal to 3 atmospheres, and the height of the column of mercury would extend to C or 60 inches above the level c. If we wish to compress the confined air into one-fourth part of its original volume, mercury must be poured in to the height of 90 inches, and then the elastic force of the confined air would be 4 times greater than at first.

It appears from these experiments that *the elastic force of air varies in exactly the same proportion as its density.* This important law, named, after its discoverer, the *law of Mariotte*, applies not only to air, but to all gaseous bodies when subject to such variations of pressure as can be readily obtained. Air has been allowed to expand into more than 2,000 times its usual bulk, and compressed into less than a thousandth of its usual bulk; but at these extreme degrees of rarefaction or condensation, it is difficult to determine its elasticity with rigour, so that it is uncertain whether the law of Mariotte applies so extensively. It is probable that when gases are subjected to very great compression, their density increases in a greater ratio than their elasticity; but Mariotte's law has been found to apply to air when condensed as much as 50 times, and also when allowed to expand to several times its usual volume.

The elasticity of the air is taken advantage of in the construction of those useful instruments, the exhausting syringe and the air-pump. The exhausting syringe consists of a brass cylinder, fig. 19, with an accurately fitting piston. The lower part of the cylinder contains two valves, one *a* opening upwards into the cylinder, and the other *b* at the side opening out into the air. The vessel V to be exhausted is screwed into a short tube projecting from the cylinder. On closing the stop-cock of this vessel and drawing up the piston, a vacuum or empty space must evidently be left between the bottom of the cylinder and the piston. Then on opening the stop-cock, the air in the vessel no longer being counterbalanced by the atmospheric pressure, expands by its elasticity, forces open the valve *a* and fills the empty space below the piston. On driving the piston forcibly down so as to condense the air the valve *a* is closed and *b* is forced open, and through this valve *b* the contents of the cylinder are expelled. When the piston has been thus forced to the bottom of the cylinder it is again drawn up, and the stop-cock being left open, the air from the vessel expands and follows it all the way; but the external air cannot enter through *b*, because this valve opens outwards, and the external atmospheric pressure only serves to close it more securely. On again depressing the piston the valve *a* is closed and *b* is forced open; and in this way the action is carried on until the air left in the vessel is so greatly expanded that its elasticity is insufficient to open the valve at *a*. The *exhaustion* of the vessel is then said to be complete. It must, however, be evident that a perfect vacuum cannot in this way be formed in the vessel. A small portion of air must always be left in it, and this portion can easily be calculated. If the cylinder be of the same capacity as the vessel, and the weight and friction of the valve be regarded as nothing, one half of the air will pass out of the vessel by the first stroke of the piston; the remaining half will still completely fill the vessel, but its atoms or particles will be further apart; its density will be diminished one half, and its elasticity will be diminished in the same proportion. The second stroke of the piston will again diminish the air in the vessel by one half, and the air left after the second stroke will have one-fourth of its former density and elasticity. The following table will show the progress of the exhaustion during nine strokes of the piston; the quantity of air in the vessel before the first stroke being taken as unity.

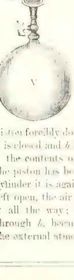
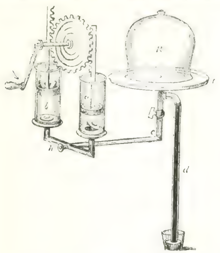


Fig. 19.

Strokes.	Quantity of air		Left in vessel.	Elastic force of Confined air.	
1st,	$\frac{1}{2}$ of 1	=	$\frac{1}{2}$	15 in. of mercury,	or 7.35 lbs per sq. in
2d,	$\frac{1}{2}$ of $\frac{1}{2}$	=	$\frac{1}{4}$	7.5 in. of mercury,	or 3.675 ,,
3d,	$\frac{1}{2}$ of $\frac{1}{4}$	=	$\frac{1}{8}$	3.75 in. of mercury,	or 1.837 ,,
4th,	$\frac{1}{2}$ of $\frac{1}{8}$	=	$\frac{1}{16}$	1.875 in. of mercury,	or 0.918 ,,
5th,	$\frac{1}{2}$ of $\frac{1}{16}$	=	$\frac{1}{32}$	0.9375 in. of mercury,	or 0.459 ,,
6th,	$\frac{1}{2}$ of $\frac{1}{32}$	=	$\frac{1}{64}$	0.4687 in. of mercury,	or 0.229 ,,
7th,	$\frac{1}{2}$ of $\frac{1}{64}$	=	$\frac{1}{128}$	0.2344 in. of mercury,	or 0.114 ,,
8th,	$\frac{1}{2}$ of $\frac{1}{128}$	=	$\frac{1}{256}$	0.1172 in. of mercury,	or 0.057 ,,
9th,	$\frac{1}{2}$ of $\frac{1}{256}$	=	$\frac{1}{512}$	0.0586 in. of mercury,	or 0.028 ,,

Hence it appears, that after the ninth stroke, the air left in the vessel will be only $\frac{1}{512}$th of its original quantity, and as it still occupies the same space, it has only $\frac{1}{512}$th the original density and elastic force, which is equal to a pressure of only 0.028lb. to the square inch, which would scarcely be sufficient to raise the valve. If however the valve *a* be fastened to the piston by a loose string, so long that it may become tightened just before the piston reaches the top of the cylinder, the string will open the valve, and the exhaustion may be carried much further.

The air pump, Fig. 20, is a double exhausting syringe, but the valve through which the air is forced out of the cylinder, instead of being placed in the side of the cylinder, as at *b*, Fig. 19, is contained in the piston or plug itself. The cylinders, or *barrels*, as they are called, are placed side by side, and motion is given to their pistons by means of a toothed wheel and racked piston rods, so contrived, that while one piston is ascending and drawing out the air, the other is descending and expelling the air already withdrawn from the vessel under exhaustion. At the bottom of each barrel is a valve opening upwards, so that during the ascent of either piston, the air below the valve forces it open and fills the barrel. During the descent of either piston this valve is closed, and the valve in the piston itself opening upwards, allows the escape of the air between the bottom of the barrel and the piston. The vessel to be exhausted is called a *receiver*, R; it is made of stout glass, with a thick rim at the bottom, which is ground perfectly smooth, and is smeared over with pomatum before being placed on the metal *tablet*, thus ensuring air-tight contact therewith. The receiver thus forms a transparent chamber, in which any substance or arrangement of apparatus adapted to the purpose may be observed under any amount of rarefaction that may be given to the inclosed air. The table is perforated in the centre with a hole which communicates by a bent metal tube *c* with the barrels *a b*. This tube has a stop-cock, which, when closed, prevents any air from leaking into the receiver from the barrels, and when open, allows them to communicate with the inclosed air. When the experiment is over, air can be re-admitted into the receiver by a hole in the bent metal tube at *h*; this hole is closed by a thumb-screw, and is made air-tight by a washer of leather. In order to ascertain the amount of exhaustion in the receiver, one extremity of a bent glass tube, *d*, opens into the metal tube *c*, and the other extremity dips into a cistern of mercury. This tube, which is more than 30 inches long, acts as a gauge, and indicates by the ascent of the mercury within it the amount of rarefaction in the receiver. As the pump is worked, the air in the receiver diminishes in density and consequently in pressure, so that the external atmospheric pressure on the surface of the mercury in the cistern forces some of the metal up the tube. The weight of the column of mercury thus raised, combined with the elastic pressure of the air remaining in the receiver, is equal to the atmospheric pressure, and the elastic force of the air in the receiver is equal to the excess of the atmospheric pressure above the weight of the column of mercury in the tube. If a common barometer stand at 30 inches, and the mercury in the gauge at 20 inches, the pressure of the air in the receiver is equal to 10 inches of mercury or one-third of that of the external atmosphere. The density of the air in the receiver is also one-third of that of the external air, showing that two-thirds of the air have been removed. In the best air pumps, the valves at the bottom of the barrels are not opened by the elastic force of the air, but by a mechanical contrivance working in the piston rods.



[illegible]

AIR-BEDS AND CUSHIONS. The elasticity of the air is taken advantage of in applying it as a stuffing material for cushions, pillows and beds. A textile fabric is rendered air-tight by the application of a solution of India rubber, and when made up into the required form, the seams are rendered tight by means of the same substance. At one corner is a short tube fitted with a screw, by loosening which the bag can be distended, and by tightening it the air is prevented from escaping. If too much air be introduced, the pillow or cushion becomes too hard, but when moderately distended, it is a tolerably soft surface. When not in use, the air can be let out and the cover folded up into a small space. The principal objection to its use arises from its great heat; air being a bad conductor of heat, the enclosed air, when made warm by contact with the body, retains its warmth and produces an unpleasant sensation of dry heat to the part which rests upon it. The water-bed or water-cushion is a much softer and cooler article, and has in a great measure superseded air-beds and cushions.

AIR-GUN. The exhausting syringe, Fig. 19, may also be used as a condensing syringe. If the vessel be removed from the end of the syringe and screwed into the short tube *b* at the side, it will be evident that on drawing the piston to the top of the cylinder, air will rush through the valve *a* and fill it. On depressing the piston, the valve *a* will close and the valve *b* will open, so that the air contained in the cylinder will be forced into the vessel V through the valve *b*, and if the vessel be strong enough it will accommodate this increased quantity of air without bursting. On again raising the piston to the top of the cylinder, a fresh supply of air will fill it, and on again depressing the piston an additional quantity will be forced into the vessel. Each succeeding descent of the piston will, however, become more difficult, for the air contained in the cylinder will not force open the valve *b* until it is more compressed than the air within the vessel, which presses up against the valve *b*. On closing the stop-cock and removing the vessel from the syringe, we have a volume of condensed air which will rush out with great force the moment the stop-cock is opened, and this force has been used for projecting balls or other missiles.

In the air-gun, the vessel for containing the condensed air is a strong metal ball furnished with a small hole and a valve opening inwards. This ball is screwed to a barrel containing a bullet, when upon turning a cock and opening a communication between the condensed air and the bullet, the latter will be projected forward with a greater or less velocity according to the state of condensation and the weight of the bullet. In air-guns, the reservoir of condensed air is usually very large in proportion to the tube which contains the ball, so that its elastic force is not greatly diminished by expanding through it, and the ball is urged all the way by nearly the same uniform force as at the first instant. The elastic fluid arising from inflamed gunpowder, on the contrary, is very small in proportion to the barrel of the gun, and occupies only a narrow space next the butt-end; so that by dilating into a comparatively large space as it urges the ball along the barrel, its elastic force is proportionately weakened, and it acts always less and less on the ball in the barrel. "Whence it happens, that air, condensed into a pretty large machine only 10 times, will project its ball with a velocity but little inferior to that given by gunpowder; and if the valve of communication be suddenly shut again by a spring after opening it to let some air escape, then the same charge may serve to impel several balls in succession. In all cases where a considerable force is required and consequently a great condensation of air, it will be requisite to have the condensing syringe of a small bore, perhaps not more than half-an-inch in diameter, otherwise the force requisite to produce the compression will become so great that the operator cannot work the machine; for as the pressure against every square inch is about 15lbs., and against every circular area of an inch diameter 12lbs., if the syringe be an inch in diameter, it will require a force of as many times 12lbs. as the density of the air in the receiver exceeds that of the common atmosphere; so that when the condensation is 10 times, the force required will be 120lbs., whereas with a half-inch bore it will only amount to 30lbs."[1]

There are various forms of air-gun, but perhaps the best is Martin's, Fig. 21. It consists of a lock, stock, barrel, ramrod, &c. of about the size and weight of a common fowling-piece. Under the lock at *b* is screwed on a hollow copper ball (*c*) perfectly air-tight. This ball is charged with condensed air by means of the syringe, Fig. 22. When the ball is charged and screwed on, and a bullet is rammed down in the barrel, if the trigger *a* be pulled, the pin in *b* will by the spring-work within the lock strike into the copper ball, and thereby suddenly pushing in the valve within it, let out a portion of the condensed air, which rushing up through the aperture of the lock, and forcibly striking on the bullet, will propel it to the distance of 60 or 70 yards, or further if the air be strongly condensed. The gun may in this way be discharged many times before the condensed air has lost its propelling power.

The air is condensed in the copper ball by screwing it to the top of the syringe. At the lower end of the rod *a* is a stout ring, through which passes the rod *k*, upon which the feet are firmly placed; the hands are then applied to the two handles *i i* fixed on the side of the barrel of the syringe, when by moving the barrel B steadily up and down on the rod *a*, the ball *c* will become charged with condensed air. The end of the rod *k* has a square hole, which with the rod serves as

Fig. 21.

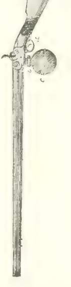
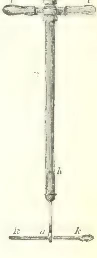


Fig. 22.



a key to fix the ball fast to the screw *b* of the gun and syringe. When the barrel is drawn up the air will rush in at the hole *h*, and when it is pushed down the air contained in it will have no other way to pass from the pressure of the air-tight piston but into the ball *c* at the top. The barrel being drawn up the operation is repeated until the condensation is so strong as to resist the action of the piston.

In other forms of air-gun there are two barrels, one of small bore from which the bullets are shot, and a larger barrel on the outside of it which forms the reservoir of condensed air: the stock of the gun contains the syringe for condensing the air. The ball is inserted by means of the rammer, and by pulling a trigger a valve is opened which allows the air to come behind the ball so as to drive it out with great force. If this valve be opened and shut suddenly, one charge of condensed air may make several discharges of bullets; but if the whole of the air be discharged on a single bullet, it will impel it more forcibly.

The air-gun is sometimes made in the form of a cane or walking-stick. Fig. 23. It is then called an *air-cane*. It is the same in principle as the air-gun, but the syringe is applied to the end of the barrel *c*, and the lock and trigger are shut up in a brass case, and when the discharge is made the trigger is pulled by pulling the chain *b*. There is a round chamber for the condensed air at the end of

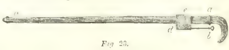


Fig 23.

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(1) Encyclopædia Metropolitana. Article, Pneumatics.

the stock at c, furnished with a valve which acts in a similar manner to that of the copper ball. When not in use the brass case d is slid off, and the instrument then becomes a walking-stick. The head of the cane unscrews at e where the extremity of the piston-rod in the barrel is shown. An iron rod is placed in a ring at the end of this, and the air is condensed in the barrel in a manner similar to that of the air-gun, but its force is not so great as in that machine.

The first notice of the modern air-gun is in the "Elemens d'Artillerie" of David Rivaut, who was preceptor to Louis XIII. of France. He ascribes the invention to Marin of Lisieux, who presented one to Henry IV. It appears, however, that Ctesibius, an Alexandrian Greek, who lived B.C. 150—120, applied the elasticity of the air to the construction of *wind-guns;* but in these machines the ball was not immediately exposed to the action of the air, but was impelled by the longer arm of a lever, while the air acted on the shorter. The air-gun is now seldom used, and indeed it must be regarded chiefly as a scientific toy, except in those cases, which we should hope are of rare occurrence, where it has been made the instrument of private revenge.

ALABASTER. See GYPSUM.

ALBUMEN or ALBUMINE, (from the Latin *albumen*, the white of an egg,) an organic nutritive principle, the chief ingredient in the white of eggs (ovalbumine), and in the fluid portion of the blood (seralbumine). It also occurs in the sap or juices of many vegetables, as the potatoe, carrot, turnip, cabbage, asparagus, &c.; in the seeds of the cereal grasses; in almonds, filberts, oily nuts, the houseleek, &c. The most characteristic property of albumine is that of solidifying or *coagulating* when exposed to a moderate heat, in which state vegetable albumine, that from potatoes for example, is not to be distinguished from boiled white of egg.

Animal albumine is that which is chiefly employed in the useful arts, and we shall confine our attention to it. The albumine of eggs and of blood is associated with certain inorganic salts and a small portion of free soda, which gives it an alkaline reaction, and renders it soluble in the animal system. Albumine deprived of its alkali is no longer soluble. Ovalbumine is a thick glairy fluid, denser than water, without taste or smell, and dissolves readily in cold water. Exposed to atmospheric air it soon putrefies, but if a thin layer be spread out and exposed to evaporation in a warm place it dries up to a pale yellow, brilliant gum-like substance, in which state it may be preserved for any length of time, the presence of water being in all cases necessary to putrefactive fermentation.

When white of egg is exposed to heat it gives out a peculiar and characteristic odour. At about 134° white fibres of coagulum begin to appear; at 160° it becomes a solid mass. At 212° it dries, shrinks, and assumes the appearance of horn. In proportion as albumine is diluted with water it requires a higher temperature to coagulate it; but water with only one-thousandth part of its weight of albumine is rendered opaque by boiling. If the quantity of albumine be so great that the liquid appears slimy, a heat of 145° or 150° is sufficient to render the whole solid, white and opaque; but in a very dilute state the albumine separates in light flocks. After coagulation albumine is no longer soluble in water, but it dissolves in caustic alkali. The only chemical change that can be traced in coagulated albumine is the loss of alkali and soluble salts, which are removed by the hot water.

From its property of coagulating by heat, albumine is used to clarify syrups, and other liquids. The albumine is first mixed with the liquid to be clarified, and heat is gradually applied; the albumine coagulates in every part of the liquid, and entangles with it all the minute insoluble substances which render the liquid cloudy, and carries them to the surface in the form of a scum which can be removed. Albumine may also be employed as a clarifier at ordinary temperatures for wine, beer, &c., in which case it unites with the tannine, and forms an insoluble compound which acts in the same manner as coagulated albumine. But for this purpose isinglass acts much better.

Albumine is also coagulated by alcohol, which unites with the water which held the albumine in solution, and it is precipitated in white filaments. It is also coagulated by sulphuric, hydrochloric, and nitric acids, but not by acetic acid, for this dissolves it. Metallic salts, such as muriate of tin and subacetate of lead, also coagulate it; bichloride of mercury, or corrosive sublimate, is on this account a delicate test of the presence of albumine, for if a single drop of the saturated solution of this salt be allowed to fall into water containing only the two-thousandth part of albumine, it will occasion a milkiness in the water, and a curdy precipitate. Albumine is an effective antidote in cases of poisoning by corrosive sublimate. It should be administered in the form of fluid white of egg, one white being required to neutralise the effect of 4 grains of the poison.

Albumine is also coagulated by voltaic electricity. If a fluid containing it be exposed to the action of a voltaic battery, soda will appear at the negative pole, and albumine will coagulate round the positive pole.

Albumine contains in 100 parts :—

Carbon	51.84
Hydrogen	7.09
Nitrogen	15.83
Oxygen	21.23
Phosphorus	0.33
Sulphur	0.68
	100.00

The presence of sulphur is shown by a boiled egg blackening a silver spoon; a trace of alkaline sulphuret being formed or separated during the coagulation.

Lime, baryta and strontia form insoluble compounds with albumine, which harden on drying. A lute formed by mixing slaked lime with white of egg, and spread on strips of paper or linen, is useful in making tight the joints of chemical apparatus.

ALCOHOL (an Arabic word) is the spirituous portion of fermented liquors, sometimes called *ardent spirit.* [See FERMENTATION, and, for its composition, ETHER. See also ACETIC ACID.] By carefully distilling fermented liquors the alcohol, mixed with a portion of water, can be separated, forming a product the properties of which differ according to the substances from which it is derived. Thus, the fermented and distilled juice of grape yields *brandy;* that of the sugar cane, *rum;* the wort of barley, which is generally malted for the purpose, yields *whisky* and *spirits of wine.* The *rectified* spirit of wine of the London Pharmacopœia contains about 82 parts of absolute alcohol and 18 of water. Its specific gravity is directed to be 0.838. To obtain pure or *absolute* alcohol, the spirit of wine must be mixed with some substance which has a strong affinity for water and little or no affinity for alcohol. Thus, carbonate of potash is a deliquescent salt; that is, when exposed to the air it attracts moisture therefrom, and dissolves, or deliquesces: it therefore has a great attraction for water; but it is quite insoluble in alcohol. When, therefore, dry carbonate of potash is added to rectified spirit of wine, the water of the spirit dissolves the salt, and forms a dense solution upon which the alcohol floats. It is not, however, quite free from water, for, when poured off and distilled, it still contains about 5 per cent. of water. Alcohol of the specific gravity of 0.835 may by this treatment be reduced to 0.815. Powdered quicklime may be substituted for the carbonate of potash with greater advantage; but it must be left for three or four days in contact with the spirit, in a well stoppered bottle, and be occasionally shaken. Chloride of calcium, fused in order to get rid of its water, may also be employed for separating water from alcohol. Equal weights of the spirit and the salt must be mixed in a well-stoppered bottle, and, when the salt is dissolved, the clear solution is poured into a distilling apparatus, and distilled at a moderate heat. About half the quantity of spirit employed must be sent over, and the process then be stopped. This will be absolute alcohol. Its specific gravity at 60° is 0.794.

There are other methods by which spirit may be deprived of a portion of its water. Thus, if a quantity of brandy or other strong spirit be put into a bladder, or into a wide-mouthed bottle and tied over with bladder, and be exposed to a temperature of from 105° to 120°, the aqueous portion will pass through the membrane in preference to the alcoholic, and in this way the spirit may be made stronger. Smugglers, who carry spirits about their persons in bladders, are aware of this fact; and this explains why their customers prefer the smuggled to the legitimate article, on account of its being stronger than ordinary spirit. Spirit of wine, of the specific gravity of 0.867, has in this way been reduced to 0.817. But by this process of exosmose absolute alcohol cannot be procured.

Alcohol is a limpid colourless liquid, of an agreeable odour and a strong pungent taste. In its pure state it is poisonous, and when diluted produces intoxication. It is extremely inflammable, burning with a pale bluish flame, the heat of which is intense. When diluted with water the heat of the flame is less intense, and its colour more yellow. It produces no smoky deposit, and the products of combustion are carbonic acid and water. According to Saussure, jun., the combustion of 100 parts of alcohol produces 136 parts of water. The intense heat of the flame and the absence of any smoky deposit make alcohol so useful in the spirit-lamp of the chemist. The flame may be coloured by certain salts: boracic acid and salts of copper give it a green colour; salts of baryta yellow; and the salts of strontia an intense red. Alcohol has never been frozen. When exposed by Faraday to a temperature of 166° below the zero of Fahrenheit's scale, it thickened considerably, but did not congeal. Hence the great use of spirit thermometers for measuring low degrees of temperature. The low temperature thus obtained by Faraday was by a mixture of solid carbonic acid and ether; but it is stated by another authority that spirit of wine, of the specific gravity 0.820, entirely congeals under similar circumstances. The boiling point of alcohol, specific gravity 0.7947, is 173°, under an atmospheric pressure of 29.5. The boiling point varies with the specific gravity, that is, it becomes higher for each addition of water. Under the exhausted receiver of an air-pump, alcohol boils at common temperatures The rate of expansion under the influence of heat is such that 1,000 measures of alcohol (specific gravity 0.817) at 50° become 1,079 measures at 170°.

Absolute alcohol has so great an affinity for water that it absorbs it rapidly from the atmosphere, and sensibly increases in specific gravity in a short time. It combines with water in all proportions; and the mixture gives rise to a diminution in bulk, and a considerable disengagement of heat in consequence of the increased density. Equal parts of alcohol (specific gravity 0.825) and water, each at 50°, when suddenly mixed, give rise to a temperature of 70°; and equal measures of proof spirit and water, each at 50°, give a temperature of 60°.

The uses of alcohol in the arts are very numerous. It can be used as a solvent in cases where water altogether fails. It dissolves resins, and hence its use in varnish-making. It does not readily unite with the fixed oils, except castor oil; but it freely dissolves the essential oils and camphor, and hence its use in pharmacy and perfumery. It dissolves sugar, soap, and oxalic, tartaric, gallic, benzoic, and some other acids. It is extensively used in the preparation of ether. From its great attraction for moisture it is employed in preserving vegetable and animal substances, and anatomical preparations. It is valuable to the chemist as a fuel, and also for many purposes of chemical analysis; but its high price in this country is an impediment in the way of science and the useful arts.

Alcohol is an agreeable stimulant in fermented drinks; but the want, suffering, and disease occasioned by its abuse far outweigh any benefits likely to be derived from its use, as forming part of a beverage. The quantity of alcohol in wine, beer, &c., is very variable. According to Professor Brande, port and sherry, and some other strong wines, contain from 19 to 25 per cent. of alcohol; the lighter wines of France and Germany, about 12 per cent. Strong ale contains about 10 per cent.; ordinary spirits, as brandy, gin, and whiskey, 40 to 50 per cent., or occasionally more. The latter owe their peculiar flavours to certain essential oils which are present in very small quantity, and are generated during fermentation, or are purposely added. The strength of such spirituous liquors as consist of water and alcohol may be judged of by the taste, the size and appearance of the bubbles, when shaken, the sinking or floating of olive oil in them, and the appearances they exhibit when burned; for, if the spirit burns away to dryness, and inflames gunpowder, or a piece of cotton immersed in it, it is considered as alcohol. "The different spirituous liquors leave variable proportions of water, when thus burned in a graduated vessel. But it must be recollected that in rum, brandy, and several other spirits, the specific gravity is often interfered with by extractive, colouring, and saccharine substances, often fraudulently added, with a view to increase the specific gravity, and therefore to diminish their apparent strength. In examining these liquors, they should be distilled, and the specific gravity of the distilled portion will then give an indication of the proportion of alcohol that may be relied on. In respect, however, to the excise, distillation is inconvenient, and is therefore only resorted to in extreme or suspicious cases."—*Brande.*

The only correct mode of ascertaining the specific gravity of liquids is by weighing them against an equal volume of pure water at the same temperature. [See GRAVITY SPECIFIC.] In practice, however, the hydrometer is used; and the form of the instrument, and the method of using it for the purposes of the excise, were given in the report of a Committee of the Royal Society to the Government. The following extract from this report will afford much useful information on this subject, especially as relates to the composition and density of *proof spirit*, which is defined by 58 George III. c. 28, to be such "as shall, at the temperature of 51° Fahr., weigh exactly twelve thirteenth parts of an equal measure of distilled water." The term *proof spirit* usually means a mixture of equal bulks of alcohol and water; but the specific gravity of such a mixture will depend upon that of the standard alcohol, which is not specified in the act referred to; but it appears, that equal weights of alcohol, specific gravity 0.796 at 60°, and water, have a specific gravity of 0.917, which is very nearly that of legal proof spirit.

The Report says:—"With regard to the substance, alcohol, upon which the excise duty is to be levied, there appears to be no reason, either philosophical or practical, why it should be considered as *absolute*. A definite mixture of alcohol and water is as invariable in its value as absolute alcohol can be. It is also invariable in its nature, and can be more readily, and with equal accuracy, identified by that only quality or condition to which recourse can be had in practice—namely, specific gravity. A diluted alcohol is, therefore, that which is recommended by us as the only excisable substance; and as, on the one hand, it will make no difference in the identification, and, on the other, will be a great commercial advantage, it is further recommended, that the standard be very nearly that of the present proof spirit.

"The proposition of your Committee is, that standard spirit be that which, consisting of alcohol and water alone, shall have a specific gravity of 0.92 at the temperature of 62° Fahr., water being unity at that same temperature; or, in other words, that it shall, at 62°, weigh $\frac{92}{100}$ths, or $\frac{23}{25}$ths of an equal bulk of water at the same temperature. The temperature of 62° Fahr. is recommended as the standard, because it is that at which water was taken in the late national survey and adjustment of weights and measures. The specific gravity of 0.92 is taken rather than 0.918633, (the specific gravity of present proof spirit at 62°,) because the fraction expressing its relation to water is much more simple, and will facilitate the construction of the tables and the verification of the instruments proposed to be used.

"This definition of standard spirit appears to your Committee to be very simple, and yet as exact as it can be, or as any other standard spirit can be. This standard is rather weaker than the old proof spirit, in the proportion of nearly 1.1 gallon of the present proof spirit per cent. But this disadvantage your Committee consider as trifling, compared with the great convenience which will result if the specific gravity of 0.92 be taken rather than 0.918633.

"It may be interesting hereafter to ascertain what proportion of absolute alcohol enters into the composition of the recommended standard spirit, should the latter be adopted by the Government; but the point possesses not the slightest practical importance in relation to the present question. The proposed standard is, in fact, more definite, more sure, and more ascertainable than that of the alcohol which it must contain. Philosophers are not yet agreed upon the density of absolute alcohol; and the differences of specific gravity assigned to it vary from 0.7910 to 0.7980. But, assuming the truth to be somewhere within these extremes, the proposed standard would contain nearly one-half, by weight, of absolute alcohol.

"In any mixture of alcohol and water, the specific gravity appears to be the only quality or condition to which recourse can be had for the practical purposes of the Excise, in order to indicate the proportion of standard spirit present. Your Committee are of opinion, that the hydrometer is the instrument best fitted, in the hands of the excise officer, to indicate that specific gravity; and they think it ought to be so graduated, as to give the indication of strength, not upon an arbitrary scale, but in terms of specific gravity at a fixed temperature, which, in the present case, should be 62°, or that of the standard spirit. The graduation, in terms of specific gravity, will not only supply a very minute, yet sensible scale, for the purposes of ascertaining smaller differences in the density than is done by the present scale, but will also afford an easy means of verifying the instruments when required."— See GRAVITY SPECIFIC.

ALE. See BEER.

ALEMBIC. A vessel used for the distillation or sublimation of substances of moderate volatility. In its simplest form it consists of a *body, cucurbit,* or *matrass,* M (Fig. 24) containing the fluid to be distilled, or the substance to be sublimated; a head or capital, H, furnished with a pipe, leading into a receiver R. Heat is applied to the body M, either by means of a lamp or a sand-bath. The rising vapour is condensed in the head, and, trickling down the sides, is received into its depressed channel C, from which it flows down the pipe into the receiver, which is loosely fitted to it by means of a ring of cork. The condensation is more rapid if the receiver be immersed in cold water. The alembic is now seldom used, it having been superseded by better forms of apparatus, which will be described under DISTILLATION.

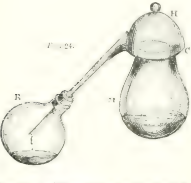
Fig. 24.

ALKALI. A term applied by the Arabians to the carbonate of soda found in the ashes of marine plants. The same term was afterwards extended to carbonate of ammonia, and also to the carbonate of potash found in the ashes of land plants, which was long considered as identical with carbonate of soda. It was discovered that these three alkaline carbonates are rendered much more caustic by contact with lime; and hence the *mild* (or carbonated) alkalies were distinguished from the *caustic* (or pure) alkalies. Dr. Black, in 1756, showed that this change is due to the abstraction of carbonic acid from the mild alkalies by the action of lime. The older chemists distinguished ammonia as the *volatile alkali* from the two *fixed alkalies,* and of these potash received the name of *vegetable alkali,* soda that of *mineral alkali,*—the one being found chiefly in the ashes of plants, the other in rock-salt. It was afterwards found that potash exists in many widely diffused minerals; and, consequently, the term *vegetable alkali* could not properly be applied to it. Klaproth suggested that the word *kali* should be used to designate it; but the French chemists invented the word *potasse* to distinguish the pure alkali, deriving the term from the German word, *pottasche,* which, probably, owes its origin to the use of iron pots in burning the materials from which the alkali is obtained. The alkalies and earths were long regarded as simple substances, although Lavoisier had suggested that they were metallic oxides. Sir Humphry Davy, in 1807, first succeeded, by means of a powerful voltaic battery, in separating the metals from potash, soda, baryta, strontia, and lime, and in obtaining traces of metallization from the earths. These results were extended and confirmed by Gay-Lussac, and others. The discovery of these metals also led to that of pure potash and soda; for, up to that time, these substances were known only in the state of hydrates, and these hydrates were long regarded as anhydrous alkalies.[1]

Alkalies have a great affinity for acids, combining with them to form salts. Alkalies in solution convert vegetable blue colours into green, and vegetable yellows into reddish brown. The infusions of red cabbage, and of turmeric, or bibulous paper stained with these substances, are used as tests for the presence of an alkali. Unsized paper, tinged by a strong infusion of the petals of the red rose, is a very delicate test for the presence of an alkali: in a very strong alkaline solution, it is turned greenish brown; but when the solution is very dilute, its reaction is very delicate, and it becomes bright green; it will thus indicate the presence of an alkali when turmeric paper is not visibly discoloured. The alkalies restore the colour of vegetable blues which have been reddened by acids; and acids restore vegetable colours which have been altered by alkalies.

No metal yields two alkalies by different degrees of oxidation, nor does any one become, by this process, an alkali and an acid. All the fixed alkalies will bear a high temperature without decomposition. They are of extensive use in various chemical arts, as in the manufacture of SOAP and GLASS.

There is a class of vegeto-alkalies, named *alkaloids,* which are produced in plants during vegetation, but always in combination with a peculiar acid. They are, for the most part, sparingly soluble in water, but dissolve in hot alcohol, from which they often crystallize, in a very beautiful manner, in cooling. Two of them, however, are oily, volatile liquids. Their taste, in solution, is intensely bitter; and their action on the animal economy is very energetic. They all contain nitrogen, and are complicated in structure. None of the organic bases occurring in plants have hitherto been formed artificially. ***Morphia*** or *morphine,* the chief active principle of morphine, and *cinchonia* and *quina,* to which the valuable medicinal qualities of the Peruvian barks are due, may be cited as examples of alkaloids.

ALKALIMETRY. A process for estimating the quantity of free alkali, or of carbonate, contained in any impure specimen. The process depends on the neutralization of the alkali by an acid, and the use of the test-papers, described in the last article. The dilute acid is usually placed in a graduated glass tube, called an *alkalimeter,* (Fig. 25,) which

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[1] Gmelin's Hand Book of Chemistry, vol. iii.

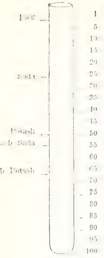

Fig. 25.

is prepared and used in the following manner, according to the directions given by Dr. Faraday in his work on "Chemical Manipulation." A tube, closed at one end, 9½ inches long, and ¾ of an inch internal diameter, is selected, and 1,000 grains of water are weighed into it. The space thus occupied is graduated into 100 equal parts, and every ten divisions are numbered from above downwards. At 23.44 parts, or 76.56 parts from the bottom, an extra line is made on the opposite side, with the word *soda* written against it with a scratching diamond. Lower down, at 48.96 parts, is another line, with the word *potash*. Still lower, at 54.63 parts, is a third line, with *carb. soda* marked; and at 65 parts, a fourth, marked *carb. potash*. It will be observed, that portions are measured off beneath these marks, in the inverse order of the equivalent numbers of these substances, and, consequently, directly proportionate to the quantities of any particular acid, which will neutralize equal weights of the alkalies or their carbonates. As these points are of importance, they ought to be verified, by weighing in the tube first 350, then 453.7, then 510.4, and, lastly, 765.6 grains of water, which will correspond with the marks if they are correct. Or the graduation may be laid down from the surface of the four portions of fluid, when weighed in, without reference to where they fall upon the general scale. The aperture of the tube should be so formed as to be perfectly and securely covered by the thumb of the left hand.

The acid used with the tube is diluted sulphuric, of the specific gravity 1.1268, prepared by mixing 1 part by weight of oil of vitriol, of specific gravity 1.82, with 4 parts of water. A quantity of this acid measured into the tube up to any one of the four marks described will neutralize 100 grains of the dry alkali or carbonate set down at the mark; consequently, if water be added in the tube thus filled up to any one of the marks, until the 100 parts are full, and the whole uniformly mixed, 1 part of such diluted acid will neutralize 1 grain of the alkali or carbonate named at the mark up to which the tube was first filled with the acid of specific gravity 1.1268.

When a specimen of potash, barilla, or kelp is to be examined, 100 grains are to be weighed out, dissolved in warm water, filtered, the insoluble portion washed, and the solution added to the rest. By this process the alkali will be separated from carbonate of lime, or other insoluble matters, which might otherwise lead to error in the estimation. The alkaline solution is to be put into a basin in the sand-bath, and the tube and acid prepared. The acid is to be poured into the tube up to the mark which indicates the substance to be tested for; *potash* or *carbonate of potash* for the potash or pearlash of commerce, and *soda* or *carbonate of soda* for barilla or kelp. Water is then added until the 100 parts are filled up, and, closing the tube with the thumb, its contents are to be perfectly agitated and mixed. Then inverting the tube, so that the thumb and mouth of the tube are downwards, the acid is to be let out gradually into the alkaline solution in the basin, by relaxing the thumb, and admitting a succession of small bubbles of air. The hot solution beneath is to be continually stirred, so as to mix the acid instantly with the whole, and increased caution must be used as the point of neutralization is approached. The acid must then be let out in portions less than a drop. This process is carried on until the alkali is found by test papers to be exactly neutralized. Then the tube must be inverted, the thumb removed by drawing its under surface over the edge of the tube, so as to leave as much as possible of the fluid that otherwise might adhere to it; and having allowed the sides to drain, it must be observed how many parts of acid have been used, the number of which will indicate the number of grains of the alkali or carbonate contained in the 100 grains of the impure alkali operated with.

The proper strength of the acid used in the above process may be ascertained in the following manner: crystals of bicarbonate of potassa are fused in a platinum crucible, and when cold a portion of the resulting solid, 70, 80, or 100 grains, is to be weighed in water, thus furnishing a known weight of pure carbonate of potash in solution. The solution is then to be diluted, heated, and neutralized by acid from the tube, diluted as before described from the mark of carbonate of potassa. If it be found that as many parts of the acid have been used as of grains of the carbonate weighed out, the acid is of proper strength; if more acid has been used, it is too weak; if less has been sufficient, it is too strong.

A process of neutralization, quite the same in principle, may be adopted for the purpose of estimating the strength of acids. This is called *Acidimetry.* ACETIC ACID is frequently estimated in this way, both because its specific gravity varies very little with its strength, and because it is much used in the arts in an impure state. As there is a very near agreement between the equivalents of acetic acid and carbonate of lime, by allowing the acid to act on fragments of marble, the quantity dissolved will at once express the quantity of pure acid present. In like manner hydrochloric, nitric, and any other acid which forms a neutral soluble salt with lime, may be estimated, and its strength become known. Thus, let 500 grains of the acid be put into a basin or flask with 100 grains of marble, in fragments, and, after the first effervescence is over, warmed, and the neutrality ascertained by test papers; the solution is then to be poured off, and the remaining pieces of marble washed, dried, and weighed. The number of grains of carbonate of lime dissolved in hydrochloric acid, multiplied by 0.74, indicate the number of grains of dry acid by which it has been dissolved; and the number dissolved in nitric acid, multiplied by 108, also represent the equivalent of dry nitric acid, or the quantity present in the solution submitted to experiment.

ALKANET. A fine red dye, obtained from the roots of a kind of bugloss (*Anchusa tinctoria*), largely cultivated about the neighbourhood of Montpellier, and in some other parts of France. The dye is procured solely from the bark of the roots, therefore young plants, in which there is more bark in proportion to the bulk of the root than in old ones, are the most valuable. The colour is yielded readily to alcohol and to all unctuous substances, but to water it yields only a dull brown colour. The principal use of alkanet is to colour ointments, lip-salve, pomade, &c. The spirituous tincture is also employed in staining white marble.

ALLOY. Chemistry has made us acquainted with about forty-three metals, of which not more than twelve are of great and extensive use in the industrial arts. These are iron, copper, lead, tin, silver, gold, mercury, zinc, platinum, arsenic, antimony, and bismuth. In this limited list platinum is always employed in a pure state; iron, copper, lead, tin, silver, gold, and zinc, are also employed in certain cases in their pure state; but in all those applications where hardness is a desirable quality two or more metals are combined, so as to form an alloy.[1] Arsenic, antimony, and bismuth are too brittle to be used in a pure state.

Although the number of useful metals is so limited, the number of alloys admits of being increased to almost any extent. Thousands of alloys are possible, but hitherto not more than two or three hundred have been made; and of this number not more than about sixty have been studied with care. As it is impossible to predict the properties of a new alloy, it remains for the scientific chemist or the manufacturer to add to our knowledge on this interesting subject.

An alloy may be regarded as a new metal, since it does not always, or even generally, represent the properties of its component parts, or the mean of those properties, which it would do if it were a mechanical mixture, as it is sometimes stated to be. The power of forming alloys is highly valuable to the manufacturer, because it enables him to create, as it were, a new metal, adapted to some of those special wants which advancing civilization is constantly suggesting to mankind. When, for example, the idea of printing with movable types had been clearly conceived, the most obvious metals for the purpose were iron, copper, tin, and lead. But the first two were found too hard, and cut the paper pressed upon them; the other two were too soft, and were flattened under the action of the printing press. At length it was discovered that by making an alloy of 1 part antimony, and 3 or 4 of lead, a new metal was produced, harder than lead, and softer than iron and copper, and which fulfilled all the conditions required. It is stated by most writers on this subject that type-metal expands, instead of contracting, in passing from the fluid to the solid state; and that, were it not for this property, type could not be cast in a mould, but that each letter must be cut separately, thereby increasing the expense of printing, perhaps a hundredfold, and diminishing the benefits of this glorious art in a far greater proportion.

The Editor has recently been led to doubt this statement, from the circumstance that the French stereotype casters cast their plates with the moulds in a vertical, instead of a horizontal, position, thereby getting a hydrostatic pressure, which assists in filling up the mould, and producing the sharpness required. In the usual method of casting type, the mould for each letter consists of two pieces of steel, kept asunder by means of a spring, but fitting accurately together when the spring is pressed between the thumb and fingers. This mould is held in the left hand of the caster; with an iron spoon in the right hand he takes up a portion of the melted metal, pours it into the mould, gives it a sudden upward jerk, in order that the metal may penetrate every portion of the mould; at the same instant he closes the mould upon the fluid mass, still further compressing it, and suddenly causing it to solidify by contact with the two comparatively large masses of metal which form the two sides of the mould. He then relaxes the spring, and shakes out the solid type. In this way eight or ten letters are cast per minute.

Now, in this operation, the fluid type-metal is made to undergo two distinct acts of compression, first by the jerk of the mould, and secondly by closing the mould upon the fluid mass, so as to compress it into a somewhat smaller space than it would otherwise occupy; and, while thus compressed, the mass of metal surrounding it chills it, and causes it to solidify. It is, we think, to this circumstance that the sharpness of type is owing, and not to its expanding in the act of cooling. There seems to be no doubt that type-metal does not contract in cooling so much as either of its constituents in passing separately from the fluid to the solid state; but that it does contract, and not expand, seems to be proved by the fact, that when small globules of molten type-metal cool, they leave a small cup or indentation at the upper part. The Editor has undertaken some experiments to determine this interesting point, and will state the results in a future article.

In filling up and bringing into contact the neighbouring parts of machinery, such as round the brass nuts in the heads of some screw-presses, lead is found not to answer, on account of its great contraction in cooling; but the alloy of lead and antimony answers very well: not, as we think, because it expands in cooling, but because it does not contract so much as lead alone.

In the example of type-metal we see that the properties of the two metals are greatly modified. Lead is a soft, malleable metal; antimony is hard, brittle, and crystalline. The alloy is flexible, harder than lead, and softer than antimony; but, by varying the proportions of the two metals, the properties of the alloy become varied also. 6 parts lead to 1 of antimony produce an alloy used for large, soft printers' types; 3 of lead and 1 of antimony produce the metal of the smaller types: the former will bend slightly, but the latter is very hard and brittle, and will not bend at all. With larger proportions of lead a flexible alloy is obtained, adapted to the sheathing of ships. In these examples the properties of the alloy are modified by the properties of the constituent metals: when the soft lead prevails, the alloy resembles lead; by increasing the proportion of antimony the alloy becomes harder and more brittle. With 4 of lead and 1 of antimony the fracture of the resulting alloy is not reluctant like lead, nor foliated like antimony, but is nearly of the grain and colour of some kinds of steel and cast-iron. So also in alloys of tin and lead, the former contributes to the alloy some of its hardness, whiteness, and fusibility in proportion to its quantity, as in the various kinds of pewter; but in this alloy, copper and sometimes zinc or antimony are introduced in small portions.

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[1] When mercury is one of the metals thus combined the combination is called an amalgam.

In these examples the properties of the constituents appear to be only modified. In other examples we get new sets of properties. Thus, copper and tin are both very malleable and ductile metals. An alloy of 9 parts copper and 1 part tin is a tough, rigid metal, used in brass ordnance, and called *gun-metal;* it admits of neither rolling nor drawing. By increasing the proportion of tin, which is much softer than copper, we actually increase the hardness of the alloy. One-sixth of tin produces the maximum degree of hardness. With one-fourth of tin the highly elastic and sonorous *bell-metal* is produced, in which the brittleness rather than the hardness is increased. 2 parts copper and 1 part tin produce an alloy so hard that it cannot be cut with steel tools, but crumbles under their action; when struck with a hammer, or even suddenly warmed, it flies in pieces like glass, and displays a highly crystalline structure. It has no trace of the red colour of copper, but is quite white, and takes an exquisite polish, not greatly disposed to tarnish: this is the *speculum-metal,* used in reflecting telescopes.

Two parts copper and one part lead produce an inferior metal named *pot-metal* or *cock-metal,* which is so soft as frequently to be broken in driving a tap into a beer-cask.

Copper and lead do not combine so readily as copper and zinc; for if the moulds be opened before the castings become cold the lead will ooze out, and appear on the surface in globules. The same thing happens to a less extent in gun-metal, where the tin "strikes to the surface," and renders it particularly hard at those parts, from an increased proportion of tin. Moulds of brass, on the contrary, may be opened while red-hot.

The properties of an alloy may also be varied by the addition of a small quantity of a third metal. For example: brass is an alloy of copper and zinc; but the best kind of brass for turning at the lathe is made by the addition of a small quantity of lead. This, however, renders it unfit for hammering, just as brass without lead is unfit for turning.

Alloys are formed in various ways. Many are prepared by fusing the two metals in a covered crucible; but if the metals differ considerably in specific gravity, the heavier one will often sink, and the lower part of the bar or ingot will differ in composition from the upper. This may, to a great extent, be prevented by stirring the alloy with a rod of pottery ware until it solidifies. An alloy of gold and copper cast into bars, the moulds being placed perpendicularly, it was found that the upper part of the bar contained more copper than the lower. Copper and silver appear to combine easily; but it is very difficult to form a bar of their alloy of perfectly uniform composition.

In casting large bells and cannons the bottom of the casting will sometimes contain too much copper, and the top too much tin. In such case the objects must be broken and remelted, and this second fusion often corrects the defects of the first. In most alloys of three metals it is best to combine them first in pairs, and then to fuse these pairs together. For example, it is not easy to unite iron and bronze by a direct method; but if tinned iron and bronze be fused together, they unite readily. When lead is to form part of the composition of brass, it is better to melt the lead and the zinc together, and then to add this alloy to the melting copper.

When the component parts of an alloy are separately fused and mingled together, great heat is generally evolved: thus, when zinc and copper are suddenly mixed, in the proportion to form brass, the increase of the heat is so great as to vaporize part of the zinc.

The specific gravity of an alloy is seldom the mean of its component parts. In some cases there is an increase of density; in others a diminution. In the following table, prepared by Thenard, the list on the left hand contains those alloys which have a greater specific gravity, and the right hand list those which have a less specific gravity, than the mean of their components.

INCREASED DENSITY.	DIMINISHED DENSITY.
Gold and zinc.	Gold and silver.
Gold and tin	Gold and iron
Gold and bismuth	Gold and lead.
Gold and antimony	Gold and copper.
Gold and cobalt	Gold and iridium.
Silver and zinc	Gold and nickel
Silver and lead.	Silver and copper.
Silver and tin.	Copper and lead
Silver and bismuth.	Iron and bismuth.
Silver and antimony.	Iron and antimony.
Copper and zinc.	Iron and lead.
Copper and tin.	Tin and lead.
Copper and palladium.	Tin and palladium.
Copper and bismuth.	Tin and antimony.
Copper and antimony.	Nickel and arsenic.
Lead and bismuth.	Zinc and antimony
Lead and antimony	
Platinum and molybdenum	
Palladium and bismuth.	

Alloys conduct heat and electricity, but less perfectly than the pure metals of which they are formed. Alloys are in general less ductile than the more ductile of their constituents. Alloys formed of ductile metals are either brittle or ductile. When formed in nearly equal proportions of their constituents, there are as many ductile as there are brittle alloys; but when one of the metals of an alloy greatly predominates, it is usually ductile. By combining ductile metals with brittle ones, brittle alloys are usually formed, if the brittle metal predominates, or even if its proportion be about equal to that of the ductile metal. But when the ductile metal is much greater than the brittle one, the alloy is nearly always ductile. All alloys formed of brittle metals are themselves brittle.

Lead, tin, or zinc, alloyed with the less fusible metals, copper, gold, and silver, produce alloys less malleable, when cold, than the superior metal, and, when heated barely to redness, they fly to pieces under the hammer: hence, brass, gun-metal, &c., when hot, require cautious treatment. Muntz's patent metal, which is a species of brass, can, however, be rolled at a red heat; but it must be remembered that the action of rollers is far more regular than that of the hammer, and soon gives rise to the fibrous character which, when uniformly distributed, is the element of strength in metals.

The strength or cohesion of alloys is in general greatly superior to that of their constituents. Thus the relative weights required to tear asunder a bar one inch square of each of the following alloys is given in the subjoined tables from Muschenbroek's investigations:—

Strength of Alloys.

10 Copper,	1 Tin	32,093 lbs.
8 ,,	1 ,,	36,088 ,,
6 ,,	1 ,,	44,071 ,,
4 ,,	1 ,,	35,739 ,,
2 ,,	1 ,,	1,017 ,,
1 ,,	1 ,,	725 ,,

Strength of Cast Metals of which the above Alloys were composed.

Barbary Copper	22,570 lbs.
Japan Copper	20,272 ,,
English Block Tin	6,650 ,,
Ditto	5,322 ,,
Banca Tin	3,679 ,,
Malacca Tin	3,211 ,,

These results show that theory and practice agree in assigning the proportion of 6 to 1 as the strongest alloy. The most reflective mixture is the weakest but one, its strength being only one-third to one-sixth that of tin, or one-twentieth that of copper, which latter metal constitutes two-thirds its amount.

In the following alloys, which are the strongest of their respective groups, the tin is always four times the quantity of the other metal; and they all confirm the remarkable fact that alloys have for the most part a greater degree of cohesion than the stronger of their constituents.

Strength of Alloys.

4 English Tin,	1 Lead	10,607 lbs.
4 Banca Tin,	1 Antimony	13,480 ,,
4 ,,	1 Bismuth	16,692 ,,
4 English Tin,	1 Zinc	10,258 ,,
4 ,,	1 Antimony	11,323 ,,

Strength of their constituent Cast Metals.

Lead	885 lbs.
Antimony	1,060 ,,
Zinc	2,689 ,,
Bismuth	3,008 ,,
Tin	3,211 to 6,650 ,,

All the metals, even the most refractory, which can scarcely be fused in a crucible at the greatest heat of the furnace, melt down with ease when surrounded by the more fusible metals. The surfaces of the superior metal are dissolved or washed down, layer by layer, until the whole becomes liquefied. Thus nickel is nearly as difficult of fusion as iron; but it is usefully employed with copper in German silver, to which it gives whiteness and hardness, and renders the alloy less fusible. Platinum is a very refractory metal, being infusible at the highest heat of a furnace; yet it combines so readily with zinc, tin, and arsenic, that it is dangerous to heat one of those substances in a platinum spoon, for an alloy would probably be formed, and the spoon spoiled.

Alloys are without exception more fusible than the superior metal which enters into their composition. Hard solders are usually made of the same metal they are intended to join, with the small addition of a more fusible metal. It may even be said that the fusing point of an alloy is generally lower than that of the *less* fusible metal which enters into its composition. When the constituent metals are nearly of the same fusibility, the alloy still fuses at a temperature lower than the fusing point of the less fusible metal. An alloy, very remarkable for its easy fusibility, is formed by combining 8 parts of bismuth with 5 of lead and 3 of tin. This alloy fuses in boiling water, and even in water at the temperature of 198° or 200° Fahr. And yet, if we calculate the fusing point by taking the mean of the fusing points of the constituents multiplied into their mass, this will give 520°, for bismuth melts at 500°, lead at 600°, and tin at 442°, and

$$\frac{8 \times 500 + 5 \times 600 + 3 \times 442}{16} = 520.$$

Sir Isaac Newton was the discoverer of this remarkable alloy, which is called *fusible metal.* His proportions were 5 parts bismuth, 3 parts tin, and 2 parts lead. By combining these three metals in various proportions, alloys are formed of various degrees of fusibility above and below the temperature of boiling water. Safety-plugs for steam-boilers have been formed in this way. A hole made in the boiler is stopped with one of these plugs, and it was supposed that if from any cause, such as the derangement of the safety valve, steam above the usual temperature and pressure be formed, it would fuse the plug of fusible metal, and thus force its way out through the aperture instead of bursting the boiler. [See BISMUTH.] If mercury be added to the constituents of fusible metal, the alloy is still more fusible, and is sometimes used for filling the hollows of decayed teeth.

When an alloy is left to itself after having been fused, it solidifies and crystallizes in a confused manner, and often separates into different layers of varying degrees of density.

In exposing an alloy which contains a volatile metal to a heat greater than that which is necessary to fuse it, it is in some cases decomposed, but generally not completely. A portion of the volatile metal is driven off, but a portion also still remains, and forms a stable compound with the less volatile metal.

Alloys are in general less acted on by the atmospheric air, than the metals of which they are composed. There are, however, certain exceptions, as for example, plumber's solder, which contains 2 parts lead and 1 part tin, burns at a red heat, and with 3 parts lead and 1 part tin it is even more combustible. An alloy of antimony and iron is so easily set on fire, that the mere action of the file is sufficient for the purpose. An alloy of chromium and lead will sometimes take fire spontaneously by mere exposure to the air, and always at a slight elevation of temperature.

When an alloy is formed of a metal which absorbs oxygen, and another which is not oxidizable, the first may be converted into an oxide, and the second retains its metallic state. This is one of the methods adopted for separating silver from lead. If both the metals of an alloy absorb oxygen, both may be converted into oxides; but if one of the two oxidizes more readily than the other, the latter may be separated almost in a pure state by suspending the operation at a certain point. In this way copper may be separated from tin.

In forming an alloy it is often necessary to protect one or both of the metals from the action of the atmosphere. Thus in combining tin and lead, resin or grease is usually put on the surface of the melting metals. In combining tin with iron, as in tinning cast-iron kettles, &c., sal-ammoniac is rubbed upon the surfaces of the hot metals in contact with each other, and thus the air is excluded; while, if any oxide is formed, it combines with the acid in the sal ammoniac, and the surface of the metal is kept bright. [See SOLDERING.]

ALUM is a double salt, of great use in the arts, especially for preparing mordants in dyeing and calico-printing. It is also used in preparing and preserving skins; in candle-making, for hardening and whitening the tallow; in paper-hanging it is mixed with the paste; and it is also of use in pharmacy.

The word *alumen* occurs in Pliny's Natural History, in which it is stated that different substances were so named, all characterised by a certain degree of astringency, and all employed in dyeing and in medicine. It has been supposed from Pliny's account that the alum of the ancients was sulphate of iron or sulphate of alumina, or a mixture of the two. The ancients do not seem to have been acquainted with our alum. It appears to have been first manufactured in the East, but at what place or period is not known. About four or five hundred years ago there was a manufacture of alum at Rochha, the Turkish name of the government which comprehends Edessa, whence the name *roch* or *rock alum*, still in use. It was also manufactured near Smyrna and Constantinople. The first alum works in Europe are said to have been established in 1460, at Tolfa, about 6 miles from Civita Vecchia, in the territory of the Pope. The first alum works established in England were at Gisborough, in Yorkshire, in the reign of Elizabeth. Pennant says that they were first discovered by Sir Thomas Chaloner, "who observing the trees tinged with an unusual colour, made him suspicious of its being owing to some mineral in the neighbourhood. He found out that the strata abounded with an aluminous salt. At that time the English being strangers to the method of managing it, there is a tradition that Sir Thomas was obliged to seduce some workmen from the Pope's alum works near Rome, then the greatest in Europe. If one may judge from the curse which his holiness thundered out against Sir Thomas and his fugitives, he certainly was not a little enraged, for he cursed by the very form that Ernulphus has left us, and not varied a tittle from that most comprehensive of imprecations. The first pits were near Gisborough, the seat of the Chaloners, who still flourish there notwithstanding his holiness's anathema." It is curious to notice after this, that in later times the proprietors of the English alum works farmed those of the apostolic chamber, and increased in various ways the benefit derived from them.[1]

The constituents of alum are sulphuric acid, alumina, an alkali and water. The alkali may be potash, soda or ammonia. Hence there are three distinct kinds of alum, depending on the alkali employed. In this country potash alum is the kind most in use. In France both potash and ammonia alum are manufactured. Soda alum occurs native in different parts of the world, especially in South America, where soda almost uniformly replaces potash; for instead of nitrate of potash, which occurs in many parts of the old continent, there are large deposits of nitrate of soda in South America.

In alum works the most important minerals employed in extracting the salt, are *alum stone*, *alum slate* and *bituminous shale*. The processes vary according to the nature of the mineral. Alum stone is of a white or greyish colour, and sometimes yellowish white. It contains all the constituents of alum. In the works at Tolfa it is obtained by blasting with gunpowder. If the stone be kept constantly moistened with water for about two months, it will fall to powder and yield alum by lixiviation. This, however, is not the method adopted. The alum stone is broken into small pieces, and piled on the top of a perforated dome, within which a wood fire is kindled. As the roasting proceeds a sulphurous odour is disengaged, owing to the decomposition of a portion of the sulphuric acid of the stone. The roasting is performed twice, the pieces of ore which were at the edge during the first roasting being put into the middle during the second roasting. The heat requires to be carefully regulated, for if too strong the calcined stone will not yield any alum, and if not strong enough, the stone does not readily fall to powder. By this operation the stone acquires a reddish colour. It is next arranged in rows between trenches of water, and sprinkled frequently so as always to be kept moist. In two or three days it falls to powder, but the watering is continued every day for a month. The powder thus produced is then thrown into a leaden boiler filled about two-thirds with water. It is frequently stirred during the boiling, and water is added as the evaporation goes on. When the solution is complete the fire is withdrawn, and the earthy matters allowed to subside. A cock is then opened,

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(1) Beckmann, History of Inventions.

and the clear liquor drawn off into deep wooden square vessels, so constructed as to be easily taken to pieces. In these vessels the alum gradually crystallizes, and attaches itself to the sides and bottom of the vessel. The mother liquor is drawn off into shallow wooden troughs, where a fresh crop of crystals is deposited. The liquor is now of a red colour, and is muddy, and the last crystals are mixed with this red substance. They are washed clean, and the mother liquor is pumped up into a trough, and used in subsequent processes. The alum thus produced is named *Roman alum*, and is highly esteemed on account of its superior purity, some other kinds of alum being contaminated by the presence of iron. Roman alum is always mixed with a little reddish powdery matter, which is easily separated. This was probably first derived from the mother liquor, and was popularly esteemed as a proof of the alum being genuine. Hence, Dr. Thomson supposes that the manufacturers add a red powder to the article after or during the process of manufacture.

Alum slate is a much more abundant mineral than alum stone. It occurs abundantly with transition slate, and is found at Whitby, and other parts of Great Britain. The alum district of Whitby consists of precipitous cliffs, bordering on the sea, and extending to a distance of about thirty miles along the coast of the German Ocean. It is a slaty rock, but sometimes occurs in balls; it is of a bluish-black colour, with a strong shade of grey. On exposure to the air, it effloresces, and acquires an aluminous taste. Being different in composition to alum stone, it requires a different treatment in the manufacture of alum from it. If it contain much lime or magnesia, it does not answer the purpose of the manufacturer. The essential ingredients are alumina and iron pyrites. The first process is to roast the ore. In Sweden, where the alum slate itself contains a large quantity of combustible matter, it is used as fuel in the roasting. A thin layer of brushwood is first covered with pieces of alum slate, and set on fire: as the combustion proceeds, new layers of alum-slate are added, in alternate layers of roasted and unroasted ore. At Whitby, coal is used as fuel. The effect of this operation is to decompose the pyrites, to convert the sulphur into sulphuric acid, and to oxidize the iron. The ore is then washed with water, to dissolve the sulphate of iron and the sulphate of alumina. For this purpose, it is put into reservoirs of wood or of masonry, and the water is left during twelve hours to act upon ore that has been twice lixiviated; the solution is then drawn off by a stop-cock in the bottom of the reservoir, and allowed to remain twelve hours on ore that has been once lixiviated. It is then left for twelve hours upon fresh ore. The solution is now saturated with sulphate of alumina and sulphate of iron, and has a specific gravity of 1.25 at the temperature of 55°. The liquor is next boiled in leaden vessels to the crystallizing point. In Sweden, the alum slate is used as the fuel, whereby the double purpose is served of evaporating the liquor and roasting the ore. During the boiling, oxide of iron falls, mixed with sulphate of lime, if lime be present. When sufficiently concentrated, the liquor is let into square reservoirs, to crystallize. Large quantities of crystals of sulphate of iron are deposited, and these are collected by drawing off the liquor into another reservoir. When all the sulphate of iron that can be separated in this way is removed, a quantity of sulphate of potash, hydrochlorate of potash, or of putrid urine, is mixed with the liquor. By this addition, alum is formed in the liquor, and it gradually deposits itself in crystals on the sides of the vessel. These crystals are collected, and dissolved in as small a quantity of boiling water as can be used for the purpose, and the solution is poured into large wooden casks. In two or three weeks, the crystals of alum cover the sides and bottom of the vessel. The hoops are then taken off, and the staves of the casks removed, and an enormous mass of alum crystals, of the shape of the cask, is left standing, as in Fig. 26. The mass is then pierced, to allow the mother liquor to run out. This is reserved for another operation, and the alum, being broken to pieces, is fit for the market.

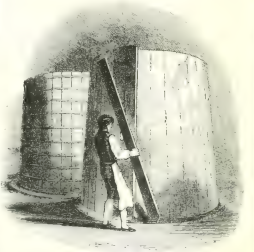


Fig. 26. ALUM CRYSTALLIZING VATS.

Another substance from which alum is manufactured is bituminous shale. This is a slaty mineral, generally accompanying beds of coal, and, consequently, is very common in Great Britain. It is of a brownish-black colour, and when heated, burns with a pale flame and a sulphurous odour, and then becomes white. In the large alum works at Campsie, near Glasgow, the shale is extracted from the old abandoned coal-pits in the neighbourhood, which are very extensive. This shale is described as a clay, mixed with some coal, and with that variety of iron pyrites which undergoes decomposition, and is converted into sulphate of iron by exposure to the air. The sulphate of iron thus formed acts slowly on the clay, and, in course of time, converts it into sulphate of alumina. During a long period, alum was formed from this material by simple lixiviation with water; and a large quantity of this washed shale accumulating in the neighbourhood of the works, it was subjected to the operation of burning, and thus made to produce a new crop of alum.

The manufacture of alum from bituminous shale and slate clay resembles the manufacture from alum slate. In the old coal-pits above alluded to, the air is moist, and the usual temperature about 62°. The shale thus exposed, during many years, has gradually opened, in the direction of its slaty fracture, so as to resemble a half-shut fan, and all the chinks are filled with a saline efflorescence. The salt, which is a mixture of sulphate of iron and sulphate of alumina, is white, with a shade of green, and has a sweetish astringent taste. The salts are dissolved by lixiviating the shale with water. The lixiviated ore being left exposed to the weather above ground, forms more salt, which is gradually washed out by the rain, and the water is collected and preserved for use. The liquor is concentrated by boiling in vessels of stone, or of brick, the heat being supplied by a current of hot air blown over the surface. When sufficiently hot, potash is stirred in, which converts the sulphate of alumina into alum. Formerly, chloride of potassium, a refuse of the soap-boilers, was used for the purpose; but of late years, at least at Hurlet, near Glasgow, sulphate of ammonia, from the liquor obtained from the gas-works, has been used. In general, the alum made at Hurlet contains both potash and ammonia; but the manufacturer can supply it free from potash. Such ammonia alum is convenient to chemists, because, when it is heated to redness, every thing is driven off except pure alumina.

When the alkali has been added, the liquor is let out into another trough, where it crystallizes; but as there is a sulphate of iron in the solution, this must be got rid of; and the method of doing so is to draw off the mother liquor at the proper time; for the alum being much less soluble in water than sulphate of iron, crystallizes first, so that the sulphate of iron is drawn off in the mother liquor while still in solution. The first crystals of alum are impure, and of a yellow colour, and partly impregnated with sulphate of iron. These are dissolved in hot water, and the solution is poured into troughs, where it crystallizes a second time. These second crystals are washed repeatedly with cold water, which separates any remaining sulphate of iron; for this, as already stated, being much more soluble in water than alum, dissolves first. These second crystals are then dissolved in hot water, and the hot concentrated solution poured into large casks, the surface of which is covered with two cross beams. As the liquor cools, a vast number of alum crystals form on the sides and surface. The casks are allowed to remain until cold, and this requires from eleven to fourteen days. The alum is then removed, and is ready for the market. The impure sulphate of iron obtained in this process is roasted at a strong heat, and when washed, yields more alum. The red residue is ground to a fine powder, and when dried, is used as a Venetian-red pigment. By altering the temperature at which it is dried, a *yellow* ochre is obtained instead of a red.

In France, where alum ores are not abundant, alum is manufactured from clay. The clay is well ground, and mixed with half its weight of the saline residue obtained from a mixture of sulphur and nitre, which is little more than sulphate of potash. The mixture is formed into balls about five inches in diameter, and calcined in a furnace. The balls are next placed on the floor of the chamber in which sulphuric acid is made. The acid vapour causes them to swell and open on all sides. In about a month they are sufficiently penetrated by the acid. They are then removed, and exposed to the action of the air, under sheds, where the saturation becomes more complete. They are then lixiviated with water, and the clear liquid, by evaporation, yields pure alum. Such is the method formerly adopted at Montpellier; but it is now found sufficient to sprinkle the balls with a quantity of sulphuric acid, of the specific gravity 1.367, equal to the weight of clay employed. The solution takes place with great facility, and crystals of alum are obtained by evaporating the liquid.

Another method is, to mix 100 parts clay with 50 of nitre and 50 of sulphuric acid. This mixture is put into a retort and distilled. Aquafortis comes over, and the residue in the retort on being lixiviated with water yields excellent alum. In 1842 Dr. Turner took out a patent for making alum from felspar.

Alum prepared by any of these processes is a white transparent salt, crystallized in regular octohedrons of which the apices are more or less truncated. Fig. 27 represents a group of crystals from one of the crystallizing tubs shown in Fig. 26.

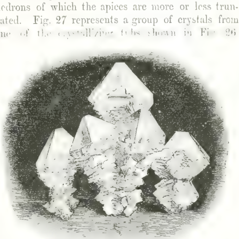
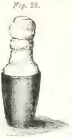


Fig. 27.—CRYSTALS OF ALUM.

12 parts of alum dissolved in boiling water with 1 part of slaked lime, yield *cubical* crystals on cooling. A slight addition of potash to a solution of alum also causes the formation of *cubic alum*, as it is called. The taste of alum is sweet and astringent, and its action decidedly acid: it dissolves metals with evolution of hydrogen as readily as free sulphuric acid. Its specific gravity is 1.72. It dissolves in about 15 parts of cold water, and in about its own weight of boiling water. The crystals effloresce slightly in a dry atmosphere; when heated they fuse in their water of crystallization at a temperature

below 212°, and when this water is driven off by heating the alum in a crucible, it swells up above the mouth of the crucible, as shown in Fig. 28, and the dry alum becomes opaque and spongy, in which state it is called *burnt alum*. Burnt alum is a mild escharotic.

Fig. 28.



Crystallized potash alum consists of 1 atom of sulphate of alumina, 1 of sulphate of potash, and 24 atoms of water; or of 1 of alumina, 1 of potash, 4 of sulphuric acid, and 24 of water.

According to McCulloch,[1] the shipments of alum from Whitby, in 1841, amounted to 3,237 tons. He estimates the produce of the Hurlet works at about 1,200 tons a year. Alum is largely manufactured in China, and is thence exported to all the western Asiatic countries. In 1837, 2,120 tons were exported from Canton.

ALUMINA is an earth of common occurrence in the mineral kingdom, in a state of silicate, as in felspar and its associated minerals, and in the various modifications of CLAY thence derived. It is the oxide of a metal *aluminum* [See Appendix], and may be obtained in a pure state by decomposing potash alum by means of carbonate of potash, repeatedly washing the precipitate with hot water; redissolving it in hydrochloric acid, adding ammonia in excess, edulcorating and drying the precipitate: it is rendered anhydrous by exposure to a red heat. Pure alumina may also be obtained by igniting pure ammonia alum previously deprived of its water of crystallization by heat; sulphate of ammonia evaporates and alumina remains in the form of a perfectly white powder, soft to the touch and insoluble in acids. Its extreme divisibility and the great hardness of its particles might render it useful for polishing metals, and its whiteness fit it for the preparation of colours. Alumina is insipid and insoluble. Its specific gravity is 2.0, but after exposure to intense heat it increases to 4.0. Under the oxyhydrogen blowpipe it fuses into a colourless bead. It has a strong attraction for moisture, which it absorbs from moist air to the amount of one-third of its weight. It becomes plastic when mixed with water: if dried in this state in the air and then heated it shrinks from loss of water. This is the principle of Wedgwood's pyrometer for registering very high temperatures; but as the shrinkage in different specimens of clay prepared in the same manner is not the same at the same temperatures, this instrument was of very little use in science. It has long been superseded by Daniell's pyrometer.

Alumina has a strong affinity for various organic compounds, and its use in dyeing and calico printing depends on its attraction for different colouring principles, and for ligneous fibre. If ammonia be added to a solution of alum in an infusion of cochineal or madder, the aluminous earth falls in combination with the red colouring matter, and the liquor is left colourless. Colours thus prepared are called *lakes*.

Freshly precipitated alumina is readily soluble in most of the acids. The salts of alumina usually have an acid reaction. Potash and soda readily dissolve it; but it is sparingly soluble in caustic ammonia. Alumina can be recognised by its solubility in caustic potash, by the formation of crystals of alum on evaporating its sulphuric solution with the addition of sulphate of potash. It also affords a fine blue colour when moistened with nitrate of cobalt and strongly heated.

Native alumina exists in the sapphire, the oriental ruby and topaz. Corundum, adamantine spar, and emery consist chiefly of alumina with a small portion of oxide of iron and silica.

Alumina consists of 2 atoms of aluminum and 3 of oxygen.

AMADOU, a fungus, (*Boletus igniarius*,) growing from the sides of the cherry, the ash, and other trees, is prepared into a tinder by the Germans, who use large quantities of it for lighting their pipes and cigars. It is gathered in the months of August and September, and cut into thin slices, and beaten with a mallet until it is soft enough to be easily pulled asunder by the fingers. In this state it is valuable for stopping hemorrhages. To convert it into tinder it is boiled in a strong solution of nitre; it is next dried, beaten again, and boiled a second time. It can be rendered very inflammable by steeping in gunpowder water. Puff balls are sometimes made into amadou, and it is stated that the light wood of the *Hernandia guianensis* takes fire readily from a flint and steel, and is used as amadou.

AMALGAM. Mercury dissolves most of the metals, and forms a class of compounds called *amalgams*. Many of these are definite crystallizable compounds, and may be separated by gentle pressure from the superfluous mercury in which they are formed. They are usually brittle or soft. Iron and mercury may be combined by rubbing together in a mortar clean iron filings and zinc amalgam, and adding a solution of perchloride of iron; by rubbing and heating this mixture, the iron and mercury form a bright amalgam. Under ordinary circumstances iron and mercury will not unite, so that mercury is imported and kept stored in iron bottles. Amalgam of tin is readily formed by triturating the metals together, or by fusion at a gentle heat; the density of this amalgam exceeds the mean of its components. It is extensively used for silvering looking-glasses. [GLASS, sec. viii.] Lead and mercury unite readily in all proportions; 3 parts mercury and 2 of lead form a crystallizable amalgam. An amalgam of 3 parts mercury, 1 part lead, and 1 part bismuth is remarkable for its fluidity; it may be squeezed through leather without decomposition. It is used for silvering the inside of hollow glass spheres, previously made perfectly clean and warm. Mercury is usually adulterated with these metals. Mercury and copper may be united by a rather complicated chemical process.

All the amalgams can be decomposed at a moderate heat. Advantage is taken of this property in the art of *water-gilding*, or gilding metallic articles, such as buttons: a small portion of gold is dissolved in a

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(1) Dictionary of Commerce, 1839.

large quantity of mercury, and the articles to be gilt being made chemically clean are anointed with the amalgam, and placed in a furnace and heated; the mercury is thus driven off, and the gold is left in an exceedingly thin film on the articles. The peculiar lustre of the precious metal is brought out by burnishing. [See BUTTON. GILDING—GOLD.] *Water-silvering* is performed in the same way. Cast-iron, wrought-iron, steel, copper, and many other metals are tinned in a similar manner. An amalgam of tin is made so as to be soft and friable. The metal to be tinned is thoroughly cleaned by filing or turning, or if only tarnished by exposure it may be cleaned with emery paper used without oil, and then rubbed with a piece of coarse cloth moistened with a little hydrochloric acid. The amalgam is then rubbed on with the same rag, and all the clean parts of the metal become thoroughly coated. This process is called *cold-tinning*, to distinguish it from the usual method of tinning iron plate. [TIN.]

In Mallet's patent processes for protecting iron from rust and corrosion, and for preventing the fouling of ships, one process is, to cover the iron with zinc. The ribs or plates for iron ships are immersed in a *cleansing bath*, formed of equal parts sulphuric or hydrochloric acid and water, used warm. The metal is then hammered and scrubbed with emery and sand to detach the scales of oxide, and to produce a thoroughly clean surface. The metal is next immersed in a *preparing bath*, consisting of a saturated solution of hydrochlorate of zinc and sulphate of ammonia; and lastly it is transferred to a metallic bath composed of 202 parts mercury and 1,292 parts zinc, both by weight. To every ton weight of this alloy is added 1lb. of potassium or of sodium, the latter being preferred. As soon as the cleaned iron has attained the point of fusion of this triple alloy, viz. 680°, it is removed, and is found to be thoroughly coated with zinc. The affinity of this alloy for iron is so intense that at the fusing heat of 680° it will dissolve a plate of wrought-iron one-eighth of an inch thick in a few seconds. When the articles to be covered are small, or the parts minute, as for example, wire, nails, or small chains, it is necessary before immersing them to permit the triple alloy to dissolve, or combine with some wrought-iron, in order that its affinity for iron may be partially satisfied, and thus diminished. In the palladiumizing process the articles to be protected are first cleansed as in zincing, and then thinly coated over with an amalgam of palladium.

A good amalgam for the use of the electrical machine is formed of 4 parts mercury, 2 parts zinc, and 1 part tin. The zinc should be melted in an iron ladle, the tin added, and afterwards the mercury, previously heated in another iron ladle, stirring the mixture with an iron rod. The amalgam should be poured, just before it solidifies, into a wooden or iron box, and be constantly agitated by shaking until cold. It should then be triturated in an iron mortar, and sifted through a small muslin sieve, so as to obtain an extremely fine powder; this being rubbed up with a little lard, is to be spread on the rubber of the electrical machine with a palate knife.[1]

AMALGAMATION. A process by which some of the ores of silver, especially the sulphurets, are reduced. The ore is washed and ground, and then mixed with a portion of common salt and roasted. Sulphate of soda and chloride of silver are formed during the operation, and these are then powdered and agitated with mercury, water and iron filings. This decomposes the chloride of silver, and the chloride of iron which is formed, is washed away; the silver and mercury unite into an amalgam, from which the excess of mercury is first squeezed out in leathern bags, and the remainder driven off by distillation. Gold is frequently extracted from its ores by the process of amalgamation.

AMBER, though classed among minerals, is of vegetable origin, bearing evidence of having been in a fluid or viscid state. It is a hard yellow substance, rather heavier than water, (its specific gravity being from 1.06 to 1.07), usually transparent when polished, but occasionally opaque or clouded. It has a resinous taste, and a smell similar to that of turpentine. It is inflammable, and gives off, while burning, a white, pungent, aromatic smoke. It possesses electric properties, which are strongly developed by friction, and which gave the name to the science of electricity, from *elektron*, the Greek word for amber. At various times the origin of amber has been a matter of dispute among naturalists, some describing it as an animal substance resembling bees'-wax, secreted by an ant inhabiting pine-forests; others maintaining it to be a fossil mineral, of antediluvian origin; and others again, with greater truth, imagining it to be a resin, oozing from the pine and afterwards solidifying. This idea was entertained by Pliny, who speaks of amber as a resinous juice, oozing from old pines and firs, and discharged by them into the sea. According to the recent researches of Göppert, amber is nothing more than an indurated resin, derived from various trees of the family of the coniferæ; which resin is found in a like condition in all zones, because its usual original depositories, viz. beds of brown coal, have been formed almost everywhere, under similar circumstances. A convincing proof that amber was once fluid is afforded by the fact that insects, leaves, drops of clear water, or portions of metal, sand, &c., are sometimes found enclosed in it. The insects are sometimes entire and in fine preservation, but frequently their detached legs and wings show that there was a hard struggle to escape from the viscid mass. Bees, wasps, gnats, spiders, and beetles, have been observed in specimens of amber; but the species more resemble insects of tropical countries than of the temperate zone. This curious circumstance of the enclosure of insects in amber has been taken advantage of by dishonest dealers, who imitate it in common copal, which closely resembles amber. Copal enclosing insects is often sold as the finest amber.

Amber is found in rounded masses, varying in size

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(1) "Electricity," by Sir W. Snow Harris, F.R.S., &c., in Weale's "Rudimentary Series."

from that of a nut to that of a man's head; but the latter is very rare. It is chiefly obtained on sea-coasts, after storms, when it is either picked up on the beach, or sought after by men who walk up to their necks in the waves, with long poles to which nets are attached; or it is gathered from precipitous cliffs by men in boats, who go armed with poles and iron hooks, and loosen fragments of rock in exploring them. The latter methods are not without danger to the amber-seekers. The most abundant supply of amber is obtained in East Prussia, along the coast of the Baltic, between Memel and Dantzig, and especially on the shore near Königsberg, and from Grossdirscheim to Pillau. It has also been found in Poland, Saxony, Siberia, and Greenland, and in our own country, at Cromer in Norfolk, and on the Yorkshire coast. Amber is also found in sand and clay formations; and, although not often obtained by mining operations, yet pits are occasionally sunk in sandy downs to the depth of 100 feet, and small quantities of amber thus procured.

Amber is used for ornamental purposes, but is much less esteemed in Europe than among Oriental nations, where the demand for it is very great. It is fashioned into necklaces, ear-rings, bracelets, &c., also into snuff-boxes, and the more costly kind of tobacco-pipes. For these purposes the nodules are split on a leaden plate at a turning-lathe, and brought into the required shape by whetstones, after which they are polished with chalk and water, or a vegetable oil, and completed by rubbing with flannel. The German pipe-makers, who use great quantities of amber, burn a small lamp or a little pan of charcoal beneath the amber, to warm it slightly while it runs in the lathe, to prevent it from chipping out: they also succeed in bending it by means of heat. The electrical properties of the amber become so strongly excited during these processes, that it is necessary to work with a number of pieces in succession, putting down each as it becomes hot, and liable to split from this cause. The workmen thus engaged are subject to nervous tremors, in consequence of handling continually these highly excited electric bodies.

The coarser sorts of amber, and the small pieces which cannot be applied to ornamental purposes, are used in making varnishes of a strong and durable kind, among which is the black varnish of coach-makers. The substance called *artificial musk* is nothing more than amber subjected to the action of nitric acid, which converts it into a viscid mass, having a musky odour. By distillation an acid is obtained from amber, called *succinic acid* (after the Latin and French name for amber). Sixteen ounces of amber yield about half an ounce of rough succinic acid, and rather more than 10 ounces of torrefied resin, fit for the preparation of varnish. The salts of this acid are called *succinates*.

Amber forms one of the most lucrative articles of commerce with Turkey, where the greater part of the European amber is sold; but considerable quantities are also purchased by American merchants. The revenue derived by Prussia from her trade in this article is said to be about 17,000 dollars per annum. The value of amber increases greatly with the size of the specimens: thus, a piece weighing 1 pound would fetch 50 dollars, but a piece weighing 12 or 13 pounds would be thought cheap at 5,000 dollars. There is a method, however, of cementing together small pieces of amber, by smoothing the surfaces, adding a layer of linseed oil, and pressing them together over a charcoal fire. Some large pieces of amber in the museum at Dresden are said to have been built up in this manner. A further deception is, to join pieces of copal to lumps of amber, when, from their close resemblance and equally fine polish, it is difficult to detect the imposition, except by the fracture, that of amber being conchoidal, that of copal of no determinate character. The most esteemed kind of amber is the opaque, which resembles the colour of a lemon, and is sometimes called *fat-amber*. The transparent pieces are very brittle and vitreous.

AMBERGRIS has no connexion with amber. It is a concretion from the intestines of the spermaceti whale, and is a product of disease, as it is not found in the healthy animal.

AMMONIA, or *volatile alkali*, so called to distinguish it from the *fixed* or non-volatile alkalies, potash, soda, &c., was first procured in a gaseous state by Priestley, who termed it *alkaline air*. He obtained it from sal ammoniac, whence the alkali has its present name.

Ammonia is a compound of 1 volume of nitrogen with 3 volumes of hydrogen, the 4 volumes being condensed into 2 in the state of combination. Ammonia exists in various vegetable and animal juices. Stale urine contains carbonate of ammonia, on which account this substance is used for its alkaline properties in making alum, scouring wool, &c. Ammonia is found in native oxide of iron, and in the rust of iron formed in a damp atmosphere. It is also found in charcoal, clays, and porous soils, all of which absorb it from the air, in which it is present in minute quantities, and is of importance to plants as a source of nitrogen.

Ammonia cannot be formed by the direct union of its elements, after they have assumed the gaseous state. One of them must be in a nascent state. There are several methods by which it may be obtained, but the following is common. The substances employed are sal ammoniac, or hydrochlorate of ammonia, and lime. The lime is slaked in a covered vessel, and the salt reduced to powder. Equal weights of these substances are introduced into a retort, with just enough water to damp the mixture and cause it to aggregate in lumps. On gently heating the retort, ammoniacal gas is given off in abundance, and this must be received in jars filled with and inverted in mercury. The changes which take place in the retort are as follows:—sal ammoniac is a compound of hydrochloric acid and ammonia; and the acid consists of hydrogen and chlorine. Lime is a compound of the metal calcium and oxygen. The hydrochloric acid of the salt unites with the calcium of the lime, forming chloride of calcium, which remains in the retort, while the hydrogen of the acid unites with the oxygen of the lime, and forms water.

The ammonia of the salt is thus set free, and escapes with a portion of the water last formed.

The ammonia thus produced is an aeriform body, which remains permanent under ordinary temperatures and pressures, and hence is called a *gas*. Under a pressure of 6½ atmospheres, at 50°, it becomes a colourless transparent fluid, of the density of 0.760, water being 1.000. At 103° below zero this liquid forms a white, translucent, crystalline solid, heavier than the liquid.

Ammoniacal gas is colourless, transparent, and invisible. It has an extremely pungent smell and an acrid taste. It instantly kills an animal immersed in it, but, when largely diluted with air, it is an agreeable stimulant. It extinguishes a lighted taper, but the flame becomes enlarged before it goes out. This gas is slightly inflammable, and a small jet of it will burn in oxygen gas. Mixed with an equal volume of oxygen, it burns with a feeble explosion in contact with flame or the electric spark. Its density is 0.5983, atmospheric air being unity. 100 cubic inches of ammoniacal gas weigh 18.268 grains. It acts strongly as an alkali, turning vegetable blues green, and yellows reddish brown; but, on account of the great volatility of the gas, this change is not permanent, the vegetable substances regain their colours by exposure to the air, which is not the case when changed by the fixed alkalies. Ammoniacal gas in a dry state is without action on dry vegetable colours.

Water dissolves ammoniacal gas in large quantity and with great rapidity. A few drops of water introduced into a jar of the gas, standing over mercury, instantly condense it; a piece of ice immediately liquefies in the gas, and condenses it. Water at 50° condenses 670 times its volume of this gas, and the density of the solution diminishes as the strength increases. When water contains 9½ per cent. of the gas, its density is 0.9692; when the water is saturated, it contains 32½ per cent. of the gas, and then the density is only 0.8750. This aqueous solution is called *liquid ammonia*, and is the *liquor ammoniæ* of the Pharmacopœia. It is a colourless, transparent liquid, and has the pungency and alkaline properties of the gas. Exposed to air, ammonia escapes from it, and heat disengages it abundantly.

The presence of ammonia is detected by its strong smell, or by holding moist turmeric paper where it is suspected to exist, or by the formation of a white vapour of hydrochlorate of ammonia when exposed to a glass rod moistened with hydrochloric acid.

Ammonia is formed during the putrefactive fermentation of organic substances which contain nitrogen. Such substances contain hydrogen, nitrogen, oxygen, and carbon; the first two forming ammonia, and the last two carbonic acid. By heating animal matters (except fat, which contains no nitrogen), such as bones, hoofs. horns, &c., in iron cylinders, they are decomposed, and carbonate of ammonia is obtained, either in a solid form, or dissolved in water, and mixed with an empyreumatic oil. This liquor has a dark colour, and a pungent, disagreeable smell. When purified to separate the oil it is called *spirit of hartshorn*. The hard portion of the bone consists chiefly of phosphate of lime, which yields no ammonia; but mingled with it is a considerable quantity of gelatine, whence the ammonia is derived.

Those vegetable substances which contain nitrogen, such as the gluten of wheat, furnish ammonia by being heated. The soot of chimneys contains it. But the great supply of ammonia is from the gas-works, the ammoniacal liquor which comes over with the tar, during the destructive distillation of coal, being converted by various processes into sulphate, hydrochlorate, or carbonate of ammonia. [See GAS.]

Ammonia combines with acids, and forms salts, most of which are soluble in water, and evolve the odour of ammonia when mixed with lime or potash. Common smelling-salts are the sesquicarbonate of ammonia.

ANALYSIS, (CHEMICAL.) The object of chemical analysis is to determine the nature or composition of simple or compound substances. The composition of a substance may either be expressed in the simple elements which form its *ultimate* constitution, or it may be reduced to less complex compounds which form its *proximate* constituents. In a chemical analysis the proximate constituents are those which are usually separated. For example, alum is composed of four bodies which are in themselves compound, namely, *alumina*, *potash*, *sulphuric acid*, and *water*; and each of these consists of a pair of elementary bodies; namely, alumina is composed of *aluminium* and *oxygen*; potash, of *potassium* and *oxygen*; sulphuric acid, of *sulphur* and *oxygen*; and water, of *hydrogen* and *oxygen*. In the analysis of alum, the alumina, potash, sulphuric acid and water are the substances sought, and the elementary composition of these bodies being known, the simple elementary components of alum are also determined.

An analysis may be simply *qualitative*, in which case it is limited to the number and nature of the constituents. Thus, when alum is said to consist of sulphuric acid, potash, alumina and water, the analysis is qualitative. But when the analysis embraces the proportions by weight of the constituents, it is then said to be *quantitative*. Thus, when alum is said to contain in 100 parts 33.78 parts of sulphuric acid, 9.93 of potash, 10.82 of alumina, and 45.47 of water, the analysis is quantitative.

Most good treatises on chemistry contain some instructions for chemical analysis. In the "Handbook of Chemistry," by Messrs. Abel and Bloxam (8vo 1858) a section is devoted to this subject: in the "Elements of Chemistry," by Professor Miller, of King's College, London, a number of examples are given: but the most elaborate treatises specially devoted to analysis are by Fresenius and Rose.

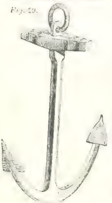
ANCHOR, (from the Greek ἄγκυρα,) a heavy instrument let down by means of a cable to the bottom of the sea for the purpose of fixing a vessel in a harbour or road, thence called an *anchorage*. It is also of great importance to the navigator off a lee shore, and in situations where, but for its use, he might be wrecked.

The anchor in some form or other is probably as ancient as the art of navigation itself, or at least it must have been used as soon as vessels of any considerable size were constructed. The first anchors were probably large stones, or crooked pieces of heavy wood, such as are used by the Chinese at the present day in securing their ponderous junks. When anchors came to be made of metal, they were formed at first with only one fluke; then a second was added, but no stock; afterwards each ship was furnished with several anchors, the chief one, which was called *ἱερά*, or sacred, being reserved for the last extremity. Hence arose the proverb, *sacram anchoram solvere*, or "flying to the last refuge," which has descended to us in the *sheet-anchor;* and in order to prevent this from being used except in cases of absolute necessity, it was formerly the custom to pay 5*l.* to the master on letting it go.

The largest ships are now furnished with seven anchors, namely, the *sheet-anchor* which, as already stated, is only let down in case of danger or during heavy gales of wind; the *bowers* or *bowyers*, which are nearly of the same size as the sheet, and distinguished as the *best bower*, the *small bower*, and the *spare anchor*. There is also the *stream-anchor*, which is much smaller than the others, and is used only for riding in rivers or moderate streams; this is one-fourth or one-fifth the weight of the others. Lastly, the *kedge-anchor*, which is half the size of the *stream*, and is only used for *kedging* in a river; that is, the anchor is conveyed by a boat up the river in advance of the ship and let down, and the ship is then hauled up to the anchor by means of the cable; the anchor is then taken up and again dropped a cable's length in advance, and the ship again moved up to it. In this way a ship may be slowly carried up a river.

In ships of war the sheet-anchor is stowed on the larboard side, with the stock vertical, and one of the flukes resting on the gangway. The bowers hang out near the ship's *bows*, and hence their name; the spare anchor is usually carried "in board." Smaller vessels, such as brigs, cutters, and schooners, have only three or four anchors.

Fig. 29.



The most common form of anchor, Fig. 29, consists of two hooked or *fluked* arms, (A, Fig. 31,) for the purpose of penetrating and fixing in the soil, and a long bar or *shank*, Sh, to which the cable is attached. To the upper or cable end of the shank is a cross-beam called the *stock*, placed at right angles to the arms, and which by lying flat at the bottom causes one of the flukes to penetrate the soil more or less according to the nature of the anchorage, as in Fig. 30. The upper end of the cable being firmly secured to the ship, any strain exerted upon the cable only causes the fluke to take a deeper and firmer hold, so that the ship is held fast unless one of three things occur; the cable may give way, the arm of the anchor may snap off, or the anchor itself may drag or plough up the soil. In some kinds of anchorage if the anchor should once start it will not take hold again; as, for example, in the Portland roads, such is the stiffness of the soil, that large lumps adhere to the fluke and prevent it from taking hold a second time. Hence the old, but absurd custom of greasing the flukes that the lumps of clay may slip off. The shank is made long in order that the stock may have greater power in directing either one or the other of the arms downwards. One end of the shank S is made square to receive and hold the stock securely in its place, and the stock is furnished with nuts or projections to keep it from shifting. The length of the square part of the shank is about one-sixth of the whole length of the shaft, and its thickness about one-twentieth. From the end of this square shank the thickness increases, but tapers towards the extremity near the arms. The part where the arms unite with the shank is called the *crown*, and the angular part between the arms and the shank is named the *throat*. A distance equal to that between the throat Thr of one arm, and its bill B, is marked on the shank from the place where it joins the arms, and is called the *trend* T. In the

Fig. 30.

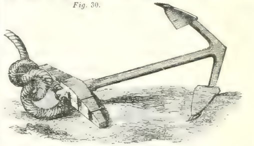
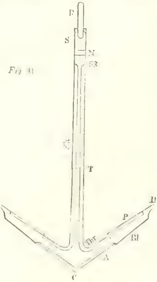


Fig. 31.



square part of the shank is a hole for receiving a ring R for the cable; this ring is lapped with cordage to prevent the chafing of the iron, but where chain cables are used, as is now generally the case, this precaution is not required.[1] The arms form an angle of about 56° with the shank, and they are made round or polygonal like the shank for about half its length, and then continued in a square shape, forming what is called the *blade* Bl. On the inner side of the blade is the *fluke* P, (also called the *palm*,) a broad, flat, triangular plate tapered to a point for entering the soil, and by its broad surface taking a firmer hold of the ground. In large anchors the arm is straight from the crown C to the *bill* B or point of the fluke, but in small anchors the internal surface is curved. The whole length of the arm is nearly half the length of the round part of the shank, and tapers slightly from the throat to the blade. The stock of the anchor is sometimes formed of two beams of oak embracing the square, and firmly united by iron bolts and hoops. The stock is rather longer than the shank, and its thickness in the middle is about one-twelfth of the length; but it tapers to about half this, the tapering being on the under surface, the upper surface being quite straight. The stock is now often made of wrought-iron, passing through the hole in the square, and retained in its place by a swelling on one side, and a key passing through a hole in the stock on the other side.

It will be seen from this construction that when the anchor is let go the weight of the arms draws the anchor downwards, and keeps it in a vertical position, and the stock moves through the water with much less resistance in the direction of its length than it would do in any other direction. The heaviest end or the crown C first strikes the ground, and then the position of the stock at right angles to the arms, its length and height above the crown, together with the weight of the cable, are sure to make the anchor *cant* or turn over with one of the pointed arms on the ground, and this effect is greatly assisted by making the anchor descend quickly, in doing which the cable is arranged in regular coils on deck, one end being attached to the anchor, and the other made fast on deck. When the word "let go" is given the fastenings are cast off, and the anchor descends, drawing the cable after it with such rapidity that it is often necessary to throw water on the hause-holes to prevent ignition.

In pulling up, or *weighing* the anchor, a heavy purchase is required, for which purpose the cable is wound round a windlass, worked by a number of hands. In doing this, the ship is gradually drawn nearly vertically over the anchor, and its shank acts as a lever for starting it out of its place, the cable drawing up the shank, and turning the whole round on the point of the fluke. The holding power of an anchor is directly as its weight; but the power of holding increases as it penetrates the ground, and keeps out water from above. The seamen seem to be aware of this, for when they swing off from the end of their handspikes, they sing out, "Heave! heave together! heave hard!—heave, and water his hole!"—that is, only raise the shank so that water may get down to the arm of the anchor, and relieve it of the superincumbent pressure.

Respecting the dimensions of anchors, there is a rough rule in the navy to allow 1 cwt. to every gun: thus an 80-gun ship will have an anchor of 80 cwt. In merchant vessels the weight of the anchors is reckoned by the tonnage: thus a merchantman of 200 tons having an anchor of 10 cwt., 5 cwt. is afterwards added for every 100 tons; so that 300 tons would give 15 cwt., and so on. The dimensions are also estimated in the navy by calling the shank 10, the arm about 3, the breadth and depth of the palm about half this, the thickness or depth at the small round .42, at the throat .6, which are nearly the dimensions of the arms also, and the breadths about $\frac{4}{5}$ths of these, the edges being rounded. The weight of an anchor 10 feet in length is about 11.4 cwt.; and, supposing all the forms of anchor to be the same, the weights would be as the cubes of the length: hence the weight of an anchor can be found by multiplying the cube of its length by .0114. This generally gives a sufficiently close approximation; but for large anchors the result is too small, because the thickness is greater in proportion. The weight of an anchor includes that of the ring. An anchor of 94 cwt. has the following dimensions:—Length of the shank, about 19 feet; of the square end to which the stock is attached, above 3 feet; the thickness of the shank varies from 8 to 12 inches; each arm is more than 6 feet in length, and the triangular fluke measures 3 feet on each side; the ring is 3 feet in diameter, and made of iron 5 inches in thickness; the stock is about the length of the shank. The cost of such an anchor would be about 300*l.*, estimating the labour at about 3*l.* per cwt., and the iron at 9*s.* 9*d.* per cwt. For anchors of 10 cwt. and under, the cost of labour is about 24*s.* per cwt.

Boats and small vessels use a form of anchor called a *grapnel*, Fig. 32, consisting of five or six hooks ranged in a circle. A modification of this is the

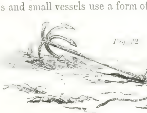


Fig. 32

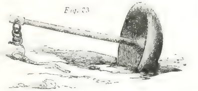


Fig. 33

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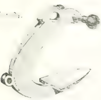
[1] On the introduction of chain cables it became necessary to improve the strength of anchors, if possible without increasing their weight. This led to sundry changes of shape, and new proportions of the metal in the different parts; among other changes the shank was shortened, and the arms were strengthened.

mushroom anchor, Fig. 33, used in the East Indies. In this form no stock is wanted, as it is sure to attach itself to the bottom, in whatever direction it descends.

Anchors have also been formed with only one arm, as in Mr. Stuard's anchor, Fig. 34, patented some years ago. To ensure the falling of this anchor the right way, with the fluke down, the shank is made very short, so that, when suspended by the cable, it will cant the most, and when it has hold in the ground the ship will ride more safely; "as a long shank," says the patentee, "is more likely to be bent, or broken from its hold." For the sake of strength, the bars that compose the separate parts are put together in one length, so that there is no weld or joining in the whole length of the shank and arm. The hole at the top is to receive the ring for the cable; another hole near it is for the stock, which is a wrought-iron bolt, covered with cast-iron at its ends. The palm is made entirely of cast-iron, or a cast-iron shell filled with lead, which is a much heavier metal than iron. A small shackle is fixed on the bend of the shank and arm, for attaching the buoy-rope.

Fig. 34.



Mr. Kingston has contrived an anchor of bell-metal, and in place of fastening the cable to a ring, it is made to pass through the centre of the shank, and is secured upon the crown by a knot of greater diameter than the tube through which it is brought.

But, perhaps, the greatest improver of anchors, of late years, is Lieutenant Rodger, who has patented two single-armed compound anchors, and a third, which has two arms. In the first, a piece of oak, saul, or teak, of the length of the anchor shank, and of proportionate thickness, is inclosed, above and below, by strong flat bars of iron, somewhat thicker towards the further end, where, at each side, a piece of iron is welded to them at the angle usual for the arms of the anchor, to bear the shank, and across the lower ends of these two latter pieces the palms of the anchor, of the common form, are also welded. At the other end of the shank, an aperture is left between the two flat bars that inclose the wooden case of the shank for the reception of the stock, which is properly rivetted and screwed firmly. Above the stock, an eye, or loop of iron is welded to the upper bar of the shank, through which a shackle passes for connecting the chain cable with the anchor, or holds a large ring for the reception of a hemp cable. This loop projects considerably from the side of the shank opposite to the palm of the anchor, in order that, when it is let go, the palm may be turned more effectually downwards, in the direction best calculated for entering the ground, by the resistance of the cable at the opposite side; and for this purpose, also, the shank is made to project some distance beyond the crown of the anchor, so as to turn the palm downwards, should the projection of the crown first come in contact with the ground.

To secure the wooden core within the flat bars at the shank, several bolts are passed through them, and the heads countersunk in one of the bars, while nuts or screws at their other ends press against the other bar. Short bolts are also fixed through the core, so as just to lie even with its sides, to prevent the looseness of the connexions, and the flat bars from approaching each other, in case the wood should decay, or be destroyed by worms.

The face of the stock farthest from the arms at each side of the shank, and the edge of the piece of iron bolted to it, are sloped so as to form an angle with the lower side more acute than the others, which when the fluke enters soft ground, causes the stock to bury itself downwards, and increase the resistance. A ring or loop is fastened to the top of the crown, for the reception of a buoy-rope, and another one is also fixed at the upper edge of the palm, in the space between the two parallel arms, through which a chain is to be passed for fishing the anchor.

In the second species of anchor, the flat plates that inclose the core of the shank are placed at the sides, instead of being fixed above and below it, as in the anchor just described. These are welded to the arms that proceed to the single palm, and are connected to each other by bolts passing through them and the core.

The third anchor (Figs. 35 and 36) has two palms and two arms, but its shank has a wooden core, inclosed, like the first, by stout flat bars, above and below, that bend off at one of its ends in contrary directions to form the arms, and to their extremities palms with flukes are welded. To strengthen these arms, a strong piece of the same curvature passes over their backs and the crown, and is welded at each

Fig. 35.

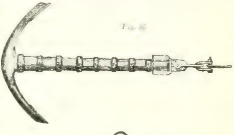
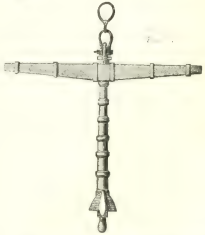


Fig. 36.



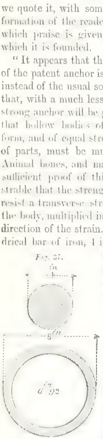
end to the palms and to the arms, and is further secured to the latter by transverse bolts. The wooden core of the shank is inclosed as before, and is also joined to the piece at the back of the arms by a strong iron band passing round the arms.

In some experiments which were made on the strength of this anchor, compared with three others of the ordinary construction, the first of the three was destroyed by a pressure of 33 times its own weight; the second by 34½ times; the third by 28½ times; and the fourth, which was Rodgers's, by 52½ times.

Among the various professional opinions which have been taken respecting the merits of this anchor, that of Mr. Seaward is so full and satisfactory, that we quote it, with some few abridgements, for the information of the reader, as a specimen testimonial, in which praise is given, together with the reasons on which it is founded.

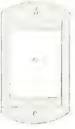
"It appears that the important distinctive feature of the patent anchor is the adopting of a hollow shank instead of the usual solid one, by which it is expected, that, with a much less weight of material, an equally strong anchor will be produced. There is no question that hollow bodies of the same weight, of similar form, and of equal strength of material, and goodness of parts, must be much stronger than solid bodies. Animal bones, and many other objects in nature, are sufficient proof of this fact. Indeed, it is demonstrable that the strength of similarly-shaped bodies to resist a transverse strain is as the sectional area of the body, multiplied into the depth of the body in the direction of the strain. Thus, comparing a solid cylindrical bar of iron, 4 inches diameter, (Fig. 37,) with a hollow cylindrical bar or pipe, 8 inches diameter, (the hollow cavity of the latter being also cylindrical, and 6.92 inches diameter, the metal being rather more than an inch thick all round,) it is clear that the sectional area of the metal in the two bars will be the same; but the capacity to resist a transverse strain in the two bars will be very different; the hollow bar will be twice as strong as the other, it being double the diameter.

Fig. 37.



"The shank of an anchor appears to be exposed to two different kinds of strain: first, that of the direct pull, or tension, and secondly, that of the transverse strain, or leverage. As regards the direct pull, the hollow shank possesses no advantage over the common shank; but, as regards the transverse strain, or leverage, which is probably by far the more dangerous strain to which an anchor can be exposed, the hollow shank, with the same weight of material, must be stronger than the solid shank, in the ratio of their respective sections in the direction of the strain. But there is one express condition, that all the parts of the hollow shank shall be equally well made, and equally well united together as those of the solid shank. The hollow shank of the patent anchor is composed of three separate pieces, as shown in the accompanying transverse section. The centre piece *a*, Fig. 38, is a square pipe or box, with two solid cheeks, *b* and *c*, placed one at the top and the other at the bottom, the three pieces being then firmly united or connected together by means of a sufficient number of strong bands or hoops. The square pipe or box is formed by four plates, disposed as shown in the section; and the cavity is filled up by a piece of hard wood, which is employed to keep the plates of the box from springing out of their proper position.

Fig. 38.



"If two four inch square bars (Fig. 39) be placed one on the other to support a weight, they will not be half so strong as a single bar, 8 inches by 4 inches, placed in the same position, because, taking the sectional area of the two bars, multiplied into their respective depths, it will amount to only 128; whereas, the sectional area of the single bar, multiplied into its depth, will be 256, twice the former; therefore the latter will be twice as strong. It is true that the two bars may be so firmly bound together, by hoops or otherwise, that the touching surfaces *a b* shall not move or slide in the smallest degree; in which case the two bars will have nearly all the stability of the single bar. On the latter principle, provided the hoops on the hollow shank prevent all motion or sliding of the surfaces, I see no reason why the shank made in three or more pieces, as described, should not be as strong as if made in one piece; but then it should be observed that an immense deal will depend upon the goodness of these hoops. I observe, however, that each end of the square box or pipe is formed solid, as shown in the longitudinal section (Fig. 40), the solid parts being firmly welded together. Moreover, these solid ends of the square box are also firmly united by welding with respective ends of the two cheeks; so that, in fact, the crown of this anchor, as also the upper end of the shank, is quite as solidly formed as in the common anchors. The hollow part of the shank reaches only from where the parts are bound together by the hoops. This is a most important advantage, and does more than anything else for the stability of the shank, by preventing the sliding of the surfaces. This, with the assistance of the hoops, renders the shank nearly as strong as if forged all in

Fig. 39.

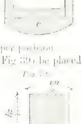
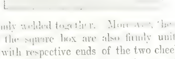


Fig. 40.



one piece, and probably stronger, from the facility of forging the parts in pieces of smaller bulk. Upon the whole, I have no hesitation in saying that an anchor with a hollow shank, made upon this plan, provided the work be well and properly executed, must be, taking weight for weight, considerably stronger than an anchor made in the common manner."[1]

In addition to the forms of anchor already noticed we must mention the *mooring anchor*, which is used for securing vessels in certain situations in harbours or roadsteads. These anchors are fixtures in the harbour, and their shape is of little consequence, compared with their powers of resistance. A mooring anchor is in some cases only a ponderous mass of stone, with a ring attached to the upper surface. In other cases, one of the largest ship's anchors, weighing 80 cwt., which has been accidentally damaged, is used, and one of the arms is beaten down upon the shank, to prevent it from entangling the cable. Hemmans' mooring anchor is of cast-iron, and very massive. The form somewhat resembles a spade, and when the edge has once penetrated the anchorage, it retains a very firm hold. Mooring anchors have a very strong iron chain, one end of which is attached to the ring, and the other supported at the surface by means of a buoy, and to which the ship is fastened.

Anchors are sometimes liable to be disturbed by a curious circumstance, namely, the formation of *ground ice*, as it is called, at the bottom of the water. The following are examples of this kind. On the 9th February, 1806, during a strong north-east wind, and a temperature of 34° Fahr., a long iron cable, to which the buoys of the fair way were fastened, and which had been lost sight of at Schappelswreck in the Baltic, in a depth of from 15 to 18 feet, suddenly appeared at the surface of the water, and floated there: it was completely incrusted with ice, to the thickness of several feet. Stones, also, of from 3 to 6 lbs. weight, rose to the surface, surrounded with a thick coat of ice. A cable 3½ inches thick, and about 30 fathoms long, which had been lost the preceding summer, in a depth of 30 feet, appeared at the surface, with a coating of 2 feet of ice. On the same day it was necessary to warp the government ship into harbour, in the face of an east wind; the anchor, after it had rested an hour at the bottom, became so incrusted with ice that it required no more than half the usual power to heave it up. Had it remained sufficiently long, and the ice accumulated upon it to a greater thickness, the probability is that it would have risen to the surface.[2]

ANCHOVY. A family of small, soft-finned fishes, related to the herring, and inhabiting principally the tropical seas of India and America. There are six or seven species, of which one (*Engraulis encrasicholus*), common in the seas of Europe, is remarkable for its fine flavour; and a second, often met with in the same localities, is occasionally sold for the same purpose, namely, to form the celebrated anchovy sauce, known since the time of the Romans, and greatly esteemed by that people under the name of *garum*. The fishing-grounds for the anchovy are the shores of the Mediterranean Sea, where this fish occurs in prodigious numbers during the months of May, June, and July, migrating thither from the Atlantic for the purpose of depositing spawn. The fishing is carried on by night, the anchovies being attracted towards the boats by means of charcoal fires kindled in the sterns. When caught, the heads, gills, and entrails are removed, and the bodies salted and arranged in small casks, of from five to twenty pounds' weight. In this state they will keep for a considerable time, supposing that proper means have been taken to keep out the air. On opening the barrel, the fish should be plump and firm, with a silvery lustre on the skin, red flesh, and a small, compact form. If this be not the case, and the fish be flabby and pale-coloured, and tapering very much towards the tail, it will probably turn out to be not the true anchovy, but another species (*E. meletta*), inferior to it in quality. Anchovy sauce is made by bruising or chopping the fish, and allowing it to simmer with melted butter over a slow fire. A little vinegar and flour are frequently added, the one to give piquancy, the other to thicken the sauce, and in this way the fish entirely dissolves, and becomes of the proper consistence for use. It is then potted or bottled, and forms the well-known condiment so much in use. Anchovies sometimes appear at the breakfast-table, whole, and are eaten with no other preparation than that which they originally received to fit them for the market. Anchovies form an important article of commerce. About 120,000 lbs. are annually entered for home consumption.

ANEMOMETER, a wind measurer, from ἄνεμος, the wind, and μέτρον, a measure. It is a matter of considerable importance to mechanical science to determine the velocity or force of the wind. Its direction is indicated by that ancient instrument the weather-cock, which consists of a vane of thin metal (formerly made in the shape of a cock, whence the name), and an arrow, turning freely at the upper extremity of a fixed vertical rod, the vane being on one side and the arrow on the other, so that the vane takes a position in the direction of the wind, and the arrow points to the quarter from which it blows. The first instrument invented for measuring the force of the wind seems to have been by Dr. Croune in 1667, which did not answer the purpose intended. Better instruments were invented by Wolfius, and other scientific men during the last century, but as their most valuable features have been preserved in modern instruments about to be described, it is not necessary to notice them here further than to state, that in most of these contrivances the velocity of the wind was measured by its mechanical effects. The compression of a spiral spring, the elevation of a weight round a centre acting at the arm of a variable lever, were the chief means employed to balance and consequently to measure the force of the wind. The spring, however, which from its simplicity has been commonly used, is liable to this objection, that it diminishes in elasticity by frequent compression, and thus the scale by which its force is ascertained must be constantly varying. To remedy this defect there has sometimes been substituted for the spring, a bag of air communicating with a glass tube in the form of a lengthened U, containing a liquid which is depressed in one leg and raised in the other in proportion to the compression of the air in the bag, thus affording a measure of the compressing force. Leslie's anemometer depended on the principle that the cooling power of a stream of air is equal to its velocity. Another instrument depended on the evaporation of water, the quantity evaporated in a given time being proportional to the velocity of the wind. The raising of a column of fluid above the general level of its surface is the principle of Dr. Lind's anemometer, *Fig.* 41. It consists of two glass tubes about 9 inches long and $\frac{4}{10}$ths of an inch in diameter, connected at their lower extremities by another tube of glass only $\frac{1}{10}$th of an inch in diameter. To the upper extremity of one tube is fitted a thin metal cap bent at right angles, so that its mouth may receive the current of air in a horizontal direction. Water is poured in at the mouth till the tubes are nearly half full, and a scale of inches and parts of an inch is placed between the tubes. When the wind blows in at the mouth of the cap, the column of water is depressed in the tube below the cap, and elevated to a similar extent in the other tube, so that the distance between the surfaces of the fluid in each tube is the length of a column of water, the weight of which is equal to the force of the wind upon a surface equal to the base of the column of fluid. The object of the small tube which connects the two larger ones is to prevent the oscillation of the fluid by irregular blasts of wind. The absolute velocity of the wind is deduced from the height of the column of water, or it may be ascertained from the tables constructed for the purpose. Thus, according to Dr. Lind, a column of water 0.025 inch, or a fortieth of an inch high, exerts a pressure of rather more than 2 ounces 1 drachm upon a square foot of surface, and balances the effect of a gentle wind moving at the rate of about $5\frac{1}{2}$ feet in a second, or not quite 4 miles an hour. When the column of water is 1 inch high, the force of the wind on a square foot is nearly $5\frac{1}{4}$lbs., its velocity $32\frac{1}{2}$ miles an hour, and its character a high wind. When the column marks 3 inches, the force is upwards of $15\frac{1}{2}$lbs. on the square foot, the velocity above $56\frac{1}{4}$ miles per hour, and the character a storm. At 9 inches the force on the square foot is stated to be 46lbs. 14 oz.; the velocity $97\frac{1}{2}$ miles an hour, producing a most violent hurricane. Thus, it will be observed that in the greatest storms, the difference between the atmospheric pressures on the windward and leeward sides of any object does not amount to $\frac{1}{30}$th of the pressure of the leeward side; for that is capable of supporting a column of about 33 feet of water.

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[1] Repertory of Patent Invent [illegible] Vol. X. 1830.

[2] Arago. Annuaire pour [illegible]

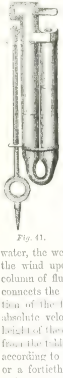
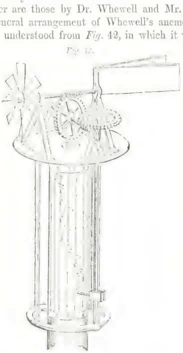


Fig. 41.

Of late years the most common forms of anemometer are those by Dr. Whewell and Mr. Osler. The general arrangement of Whewell's anemometer will be understood from *Fig.* 42, in which it will be seen that by means of a vane, a windmill fly is constantly presented to the wind in whatever direction it may blow, and the fly of course revolves with greater or less rapidity according to the velocity of the current. An intermediate train of wheels, set in motion by the fly, causes a pencil to descend over a fixed cylinder, having thereon a trace of variable length, according as the wind is more or less strong. 10,000 revolutions of the fly cause the pencil to descend only $\frac{1}{20}$ of an inch. The surface of the fixed cylinder is japanned white, and is divided into 16 or 32 equal parts by means of vertical lines, the intervening spaces corresponding to 16 or 32 points of the compass, and a mark left by the pencil upon one or more of these spaces, shows the direction of the wind. The pencil has two motions, the first from above downwards, and this increases in rapidity as the wind blows more strongly, and by the extent of its depression registers the whole amount of wind that has been blowing. The second motion depends on the changes in the direction of the wind; and the pencil and its frame being carried round by the vane, the direction is registered by this cross movement. In this arrangement, therefore, the vane, the windmill fly, the intermediate train of wheels and the pencil, all obey the direction of the wind; while the cylinder which marks the points of the compass remains fixed, so that the pencil in descending and moving about with the wind thus traces an irregular line on the cylinder. If the fly revolve in the simple proportion

Fig. 42.

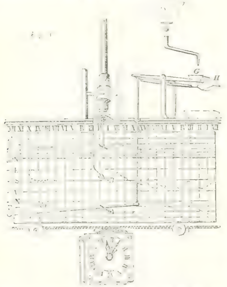


of the velocity of the wind, the length of line marked by the pencil is proportional to the space which would be described by a particle of air in a given direction in a given time, such as one day, taking into account the strength of the wind and the time for which it blows.

The line marked by the pencil upon the cylinder is not a single line, but a broad irregular path. This is occasioned by the wavering of the wind. The vane is in almost constant motion, swinging to and fro through an arc often not less than a quarter of a circle; but the middle of the line which gives the mean direction can readily be ascertained, while the length of the line is in proportion to the product of the velocity of the wind and the length of time during which it blows in each direction, which product is called its *integral force.*

The amount of friction in this machine is very considerable, arising from perpetual screws working in toothed wheels, for the purpose of converting the rapid motion of the fly into a slow, descending, vertical motion, again carried out by a thread turning within a movable nut. There is also the friction of the pencil attached to this nut pressing with sufficient force so as to leave a trace on the fixed cylinder. Hence when the force of the wind is small the fly would experience a greater amount of comparative retardation than with strong gales.

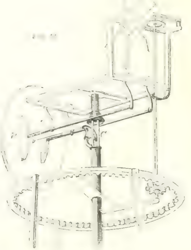
Osler's anemometer traces the direction of the wind and its pressure on a given area, together with the amount of rain, on a register divided into 24



portions, corresponding to the 24 hours of the day. A portion of one of these register papers is shown in Fig. 43, the central part of which is marked with a series of lines corresponding to the cardinal points of the compass. This is for indicating the direction of the wind. The upper portion of the paper registers the pressure, and is graduated by a series of lines corresponding to the pressure in pounds on the square foot. The lower portion of the paper registers the quantity of rain. The whole length of the paper is divided, for the hours of the day, into 24 parts by lines crossing the former at right angles. A new register paper is placed on a board, and accurately set every day, and the board is carried along by means of a clock mechanism, behind three pencils A, B, C, which may be considered as the fingers or indexes of the machine. The board, which is placed upright as in the figure, moves on friction-rollers, and is thus moved along as the time advances.

The pencil B is the index of direction. The method by which the instrument is turned so as to obey the direction of the wind will be seen in Fig. 44. A set of vanes or sails revolve vertically in a plane at right angles to that of the pressure plate P, and drive a cog-wheel, which by rolling on a fixed cogged circle, turns all the rest of the apparatus round till the vanes are presented edgewise to the current, so as not to be turned by it either way, when the pressure plate being at right angles to the vanes is acted on with full effect. As the vanes turn in the direction of the wind, a spiral worm on the shaft near its lower end raises or lowers the nut I, Fig. 43, which does not turn round, and from which hangs the arm carrying the middle pencil B, which thus traces a mark on one of the long lines of the register if the wind be blowing towards one of the cardinal points, or a mark between these lines, if it be blowing from intermediate points, such as NN.W., N.W. &c., which may be represented by fainter lines parallel with the others.

The method by which the pressure plate P, Fig. 44, is always made to face the wind, has been already described. This plate is suspended by means of 4



flexible springs, each of which is double, and consists of a delicate spring to be acted on by gentle winds, and a stronger one to receive the pressure of violent winds. By this means currents of only 1 mile an hour are measured, and the pressure of the wind in violent gales also recorded. The motion of the plate is communicated to the register below by a wire connected with the bell-crank C, with another wire descending through the hollow upright shaft and kept stretched by a spiral spring. To this wire is attached the upper pencil C, which thus descends lower the more the pressure plate P is pushed back, and returns to the top of the paper when the pressure ceases. The distance to which the pencil is thus depressed, represents, by means of a scale of parallel lines, shown in Fig. 43, the pressure of the wind in pounds on the area of 1 square foot, or its velocity in miles per hour.

The pencil A registers the rain in a similar manner. The rain after falling into the vessel D on the roof flows into G, one of the two divisions of a gauge balanced on an axis and supported by a second balance. As the water accumulates, this second balance begins to descend, and so raises the upright rod to which the lever F A is attached. This lever F A carries the pencil, which by this action is raised, showing upon the lowest set of parallel lines the quantity of water collected in the gauge. When this quantity becomes equal to a certain depth of rain or to a certain number of cubic inches on a foot square, the small gauge oversets, the water is discharged, and the other compartment H of the gauge is brought under the pipe. The pencil then returns to its first position at the bottom of the paper, and begins to rise on the scale as the rain is collected. In a trace of this kind it will be seen that the more rapidly the rain falls, the sharper will be the angles formed by the trace of the pencil; but if the rain be slow and gradual, the elevating or diagonal lines will be drawn out into a considerable length; and when no rain falls a horizontal line will be drawn, as shown in Fig. 43, from VI to ¼ after VIII, and from X ½ to I.

It will be seen, then, from this arrangement, that as the register is constantly and hourly moved along behind the three pencils, a continued record or trace of the direction and pressure of the wind, together with the amount of rain, is left on the paper. Figs. 43 and 44 are intended to convey a general idea of Mr. Osler's arrangement in the Royal Exchange, London, where the register paper is made to last a week. When the Editor visited the Meteorological Observatory at Greenwich a few years ago, he noticed that the register was placed horizontally on a table, and being on a larger scale, it was changed every day.

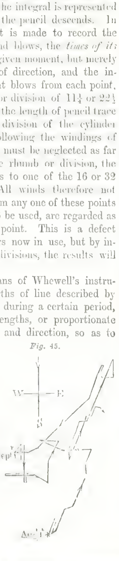
By means of such an instrument we ascertain the *direction*, the *duration*, and the *force* of the wind. It is necessary, however, for the purposes of science that the *integral* of the wind be deduced for each point of the compass; that is, to ascertain the entire quantity of wind which has blown from each point during a given period. Now if the force of the wind were constant, the integral would be obtained by multiplying the length of time that the wind is blowing, by the velocity with which it moves.

The integral of the wind, or the total quantity as measured by its intensity and duration jointly, may be thus illustrated. If the intensity or force of one wind be to that of another as 2 to 3, and if the former wind last 6 hours, and the latter only 2, the integral of the former is double that of the latter, for it has blown twice as much air over the place; for supposing the second wind to be opposite to the first, it must blow for 4 hours before it will carry back all the air which the first had blown over. The integral, therefore, is proportional to the product of the mean intensity, or velocity, and the duration multiplied together.

In a similar manner the area of a rectangle is proportional to its length and breadth taken jointly. Now if we have such a figure whose length represents the *duration* of the wind, while its breadth represents the *force* or *velocity*, as this force is constantly varying, the breadth of the figure must also vary, in order that its area may still represent the *integral* of the wind correctly. It is the object of Osler's anemometer to describe such a figure. In Whewell's instrument, on the contrary, the integral is represented simply by the depth which the pencil descends. In this instrument no attempt is made to record the *time* during which each wind blows, the *times of its changes*, or its *force* at any given moment, but merely the order of its changes of direction, and the integral or entire quantity that blows from each point, or rather from each rhumb or division of 11¼ or 22½ degrees. This is known by the length of pencil trace described in each vertical division of the cylinder measured vertically, not following the windings of the track. These windings must be neglected as far as they are confined to one rhumb or division, the centre of which corresponds to one of the 16 or 32 points of the compass. All winds therefore not deviating more than 5⅛° from any one of these points if 32 be used, or 11¼° if 16 be used, are regarded as blowing exactly from that point. This is a defect common to all anemometers now in use, but by increasing the number of subdivisions, the results will be more accurate.

Having obtained by means of Whewell's instrument the integrals, or lengths of line described by the pencil in each division during a certain period, we may lay down these lengths, or proportionate ones, in their proper order and direction, so as to form a continued crooked line, which expresses all the quantities and changes of the wind, and is called the *type* of the wind for that particular place and period. Fig. 45 represents the type of all the wind that blew over Plymouth during the month of August and part of September, 1843. Such a line may be regarded as the path that would have been described by a vessel drifting upon a still lake during that period,

Fig. 45.



provided it moved with a speed always bearing a constant ratio to that of the wind. If the two ends of this line be joined by a straight line, this will show the direction of the *resultant*, or average effect of all the winds felt at Plymouth during that period; which in this case is N. 23° E., or about equivalent to a SS.W. wind. This average direction is not the *prevailing* direction of the wind, or that in which it most commonly blows; for the prevailing winds may be very gentle, and the greater force of those from the opposite quarter may more than compensate for their shorter duration, so that the average direction as regards the integral, or time and intensity taken jointly, may be very different, or even opposite to the average direction if time alone be considered. In this country, however, both these averages have nearly the same direction; the latter, or time-average, being equivalent to a wind blowing from some point between S. and W.; and the former, or true average, though apparently very variable when the resultants of different months or seasons are compared, yet in the type of a whole year, its general direction is found invariably to run northward, and mostly eastward from the starting point. In the present state of the inquiry there is some discrepancy between the results obtained by different instruments; Whewell's placing the mean direction for three years nearer N. than E., while Osler's makes it nearer E. than N. The latter is more likely to be correct, because in Whewell's instrument the velocity of the windmill fly does not bear a constant ratio to that of the wind, but is more than proportionally faster in a quick than in a slow wind, so that the distance which the pencil descends being proportional to the revolutions of the fly, cannot correctly represent integrals of wind; that is to say, the spaces through which it descends during two successive periods do not necessarily bear the same ratio to each other, as do the quantities of wind that have passed over the instrument during these two periods. This objection is surmounted in Osler's instrument, which is driven by a clock, and merely directed or regulated by the wind.

But if Osler's instrument is more correct than Whewell's, it is more difficult to represent the results in the useful form above described. If the instrument be in perfect order, the upper trace made on the paper by the pencil c should be such that its ordinates[1] are proportional to the velocity of the wind; that is, the ordinates at any two different moments should bear the same ratio to each other, as did the velocities of the wind at these two moments. In this case the total amounts of wind passing over the instrument during different periods, will be proportional to the areas of the portions of curve traced during those periods; that is to say, the spaces contained between the curve, the base line, and the two ordinates at the beginning and end of each period. It is only by measuring and comparing these areas that we can obtain the proportion of the integrals of wind during different periods of time.

To lay down a type of the wind similar to Fig. 45, we must divide the periods in such a manner, that during each period in which the direction of the wind may have been constant, or confined within certain limits, such as two rhumbs, or 22½°, or one rhumb, 11¼°. For this purpose that part of the register paper which registers *direction* must be divided by 16 or 32 longitudinal lines, such that when the vane points to any one of the 16 or 32 principal points of the horizon, the pencil B may rest midway between two of these lines. We must then note all the points where the pencil track intersects these lines, and from every such intersection raise a perpendicular to the top of the paper; these perpendiculars will evidently divide the upper curve, or that of force, into portions, each of which may be regarded as belonging to one wind only, for during its description the wind did not deviate more than 5⅝°, (if we use 32 points, or 11¼°, if we use only 16,) on either side of a certain point. By ascertaining the areas of these different portions, and drawing lengths of line proportional to those areas, placing those lines in their proper directions, and in their proper order, we may obtain a type of the wind more correctly than by the method before described.

The integrals of the wind have hitherto been referred to only as relative quantities, admitting of comparison only with each other. They have, however, absolute values easily comparable with our common standards or measures. If a pressure plate, acting on a spring, as in Osler's anemometer, be fixed to one extremity of a long beam, or some machine by which it could be moved through the air with any required velocity between 1 mile and 50 miles an hour, it matters not whether the path be straight or circular provided the plate always face the direction in which it moves. If the air be still, the effect on the plate is the same as if it were at rest, and received a wind of a known velocity upon its surface. By this means it can be discovered what velocity of wind is required to produce any amount of compression in the spring, such as may be obtained by placing weights of known value on the pressure plate. In this way a scale of the velocities or force of the wind may be constructed, and absolute values in miles may be assigned to all the lines which compose any type of the wind; and on measuring by the scale thus obtained, the length of the resultant or line joining the two ends of the type, we thus obtain not only the direction, but also the extent in miles of the entire movement of air produced by the combined effect of all the winds that have blown during the period for which the type was constructed. In this way it was ascertained that the resultant of all the winds that blew over Greenwich during the year 1841, was equivalent to the passage of 17,900 miles of air towards E. 2[illegible] N. In 1842 the direction of the resultant was E. 27° N., and its length [illegible]750 miles. By dividing these numbers by the number of hours in a year, the total effect of the wind in 1841 is found to be equivalent to a constant current towards E. 28° 30′ N., at the rate of 5.4 miles an hour; and in 1842 towards E. 27° N., at the rate of 4.2 miles an hour; or in other words, as if there had blown during these two years a constant wind from W. S. W. ½ S. at 4¾ miles an hour.

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[1] The [illegible] of any point of the curve [illegible] perpendicular [illegible] from [illegible]

But the average velocity of the winds at Greenwich during the former year was 18.7, and during the latter, 18.3 miles an hour; for the whole integrals of wind for those years, as shown by the length of their type line, measured along all its windings, was in 1841 no less than 167,322 miles, and in 1842, 159,950 miles, showing that the whole movement of the air in this country is about 4 times as great as its resultant or effective movement. The more variable the wind may be at any place, the smaller the proportion of it that will be effective; and if these observations could be made on the open ocean within the range of the constant trade winds, the type would probably be a straight line, and the numbers expressing the total and resultant integrals of wind would be equal.

The direction or length of the resultant for any given period may be obtained more simply than by laying down such a type as Fig. 45, for as the lines, in whatever order they may be placed, will eventually lead to the same point, the figure may be simplified by collecting and summing up all the integrals that belong to the same wind or point of the compass, or that fall within the same angle of 11¼° or 22½°, but the smaller the angle the better, and then drawing lines proportional to the 16 or 32 sums thus obtained, which lines placed in any order, but in their proper directions, will give the same resultant as if the whole type were drawn. But as some of the lines thus drawn are parallel to others, it is not necessary to draw more than half of them, subtracting from each one that which is parallel to it. So that whatever number of points be used, the number of their integrals can always be reduced to one half, by subtracting each non-effective wind, or each one that is less than its opposite, from that opposite, the remainder being alone retained. Thus, Fig. 46 contains all the effective lines of Fig. 45 treated in this manner, and gives the same direction and length of resultant, by which means much labour is saved.

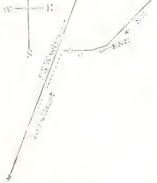

Fig 46.

There are methods of finding the resultant by calculation, for which we must refer to other works, and especially to Sir W. Snow Harris's Report to the British Association in 1844, on the working of Whewell's and Osler's Anemometers at Plymouth in the years 1841, 1842, and 1843. The Editor has also to acknowledge the use he has made in this article of a small work of his, entitled "The Tempest," published in 1848, under the direction of the Committee of General Literature and Education, appointed by the Society for Promoting Christian Knowledge. The reader interested in the subject will do well to consult the Reports of the British Association, and also the Meteorological Reports of the Greenwich Observatory. [See APPENDIX.]

ANNEALING, (from an Anglo-Saxon word *Anælan*, to heat or to burn.) From the constant tendency of the English to abbreviate words in common use, this term has been contracted by workmen into *nealing*. Annealing is a process used in the manufacture of GLASS and also of certain metals. In the glass manufacture it consists in placing the articles of glass while hot in an oven called the *leer*, where they are allowed to cool gradually. They would otherwise be too brittle for use; for the slightest scratch is often sufficient to cause unannealed glass to break, and even to fly to powder, while it will often resist a considerable blow. The curious properties of unannealed glass can be exhibited by means of the *Bologna phial* and *Prince Rupert's drops*. The former is a rudely shaped phial 3 or 4 inches long, about an inch in diameter, and the glass is about ⅛ or $\frac{1}{10}$ of an inch thick. If we drop into this phial a pistol bullet from the height of 2 or 3 feet it will not break it, or we may strike it a hard blow on the outside with the handle of a hammer without producing fracture, but if a grain of sand or a sharp bit of flint be allowed to fall into it, it will crack and fall into fragments. This effect is in some cases produced immediately, but in other cases, several minutes elapse before it takes place: and when we think the experiment has failed and are about to drop in another bit of flint, it will suddenly fly to pieces. This remarkable property seems to be destroyed by age, for among some apparatus which has come into the possession of the Editor, are a number of Bologna phials at least 50 years old, some of which have lost this property; but some specimens which will not break by a particle of flint, fly to pieces on scratching the interior surface with a file. Fig. 47 is a copy, one half of the size of the original of one of these phials which have lost this property. It would seem that during the long period in

which it has been preserved in a warm room, a slow and gradual, but partial annealing has taken place.

Prince Rupert's drops are so called from their having been first brought to England by Prince Rupert, and exhibited before Charles II. in 1661. They are also called *lacrymæ vitreæ*, or glass tears. When melted glass is allowed to drop into water it forms a globular portion at one extremity, and gradually tapers into a small tail at the other. (Fig. 48.) The greater number burst in the water, but those which remain entire exhibit all the properties of unannealed glass in a high degree. They will bear a smart stroke on the thick end without breaking, but if a small piece be snapped off from the tail, the whole will burst into powder with a smart crack. Under the exhausted receiver of an air-pump they appear to explode with more violence than in the air, and the powder is finer. If the Bologna phial or these drops be cautiously heated and slowly cooled, these peculiar properties are lost.

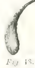
Fig. 48.

There are a few substances in nature which increase in bulk in passing from the fluid to the solid state; water and glass are examples. When glass is allowed to cool slowly, its particles arrange themselves in such a way as to form a fibrous texture, producing an elastic substance, and one susceptible of long continued vibrations; but when a quantity of melted glass is suddenly cooled, the surface first crystallizes and forms a solid shell or coating round the interior fluid parts, thereby preventing them from expanding as they become solid. This causes them to be compressed together with little mutual cohesion. Thus in the Prince Rupert's drops it is evident to the eye that the inner substance is cracked and divided into a multitude of detached parts, held together by the smooth external coat. These internal particles tend to press outwards so as to occupy more space, but are prevented from doing so by this external coat. In consequence of this effort to expand, the greater number of glass drops burst in cooling; those which remain entire may have a thicker external coat than those which burst; they will bear a smart stroke upon them, because each drop on being struck vibrates as a whole, and does not transmit its vibrations from the exterior to the interior; but if the tail be broken off, a vibratory movement is communicated along the crystalline surface without reaching the internal parts; this allows them some expansion, and thus overcoming the cohesion of the thin outer shell, the glass is burst and dispersed in powder. In unannealed glass vessels, such as a drinking glass, the same thing occurs. If such a vessel be struck or thrown into vibration, the vibrations may continue for a considerable time before the internal parts overcome the resistance. If the vessel be thin, the regular crystallization of the surface may extend through the whole thickness, or the quantity of compressed matter in the middle may be so small as to be incapable of bursting the external crust. It often happens that a wine glass or other article of irregular form breaks in cooling, simply from its unequal contraction at different parts.

Some writers regard the external crust as a hollow arch enclosing a quantity of loose materials, and the effect of scratching this crust or breaking off a portion of it, to be the same as suddenly pulling out one of the voussoirs, whereby the whole system falls to pieces.

In the process of annealing, glass is kept during many hours in a state approaching the fluid; the heat increases the bulk of the outer or crystalline portions, and renders it so soft that the interior parts can expand and crystallize regularly. Mr. Pellatt has shown experimentally that a re-arrangement of particles does occur in annealing. Two pieces of the same length of tube, each 40 inches long, were the subject of trial. One piece that was sent through the leer, contracted $\frac{1}{16}$ of an inch more than the other which was cooled as in the open air. The Editor has also noticed that the fragments of a Bologna phial when put together do not fit, as the fragments of annealed glass do.

Lamp glasses, tubes for steam gages, and similar articles which are exposed to sudden transitions of heat and cold, may be more perfectly annealed than is done in the glass-house, by placing them in a vessel of cold water, and raising it slowly to the boiling temperature, and keeping the articles for some hours at that heat, and then allowing the whole to cool very slowly. Articles of flint-glass which have to be cut are, when found to be imperfectly annealed, subjected to this process, which is found preferable to passing them a second time through the leer. A lamp-glass is much less exposed to fracture after it has been once used, because the heat, if not too suddenly checked, completes the annealing.

The process of annealing is extensively employed for softening the malleable metals, which, under the action of the hammer or of the roller, have gradually increased in hardness and elasticity and in density from the close approximation of their particles. Steel often becomes remarkably hard and dense in the process of *hammer hardening*, or hardening without heat, which is frequently the only means of hardening some kinds of steel springs. In some descriptions of steel goods, which are formed by the hammer and then required to be filed into shape, as in scissors, or teeth to be cut as in files, the metal is softened by annealing. So also in the process of wire-drawing, the metal is greatly increased in hardness and elasticity, which if not removed from time to time by annealing, would prevent the extension of the wire, and render it too brittle to be applied to any useful purpose. In rolling or flattening metals, the working and annealing are alternately repeated until the sheet reaches its limit of tenuity. The brazier who forms vessels of copper and brass solely by the hammer, can work on them only for a short time before they require annealing.

Articles of iron and steel are sometimes annealed by piling them in an open fire, and raising them slowly to a red heat: they are then left to cool gradually. This method is injurious on account of a scale of oxide which forms on the surface, thereby depriving the steel of a portion of its carbon, which confers the property of imparting a keen edge, so essential to cutting instruments. Articles of iron and steel ought to be annealed in close vessels, or in a trough or recess made of fire brick, and covered up with ashes or clean sand; or if a small vessel be employed, the cover may be of the same material as the vessel. The oven or trough is heated by the flame of a furnace passing under and round it until the whole is at a red heat. It is then allowed to cool without letting in the air. Goods thus treated become softer than by the common method, and the surfaces have a metallic whiteness imparted by the carbonaceous matter of the ashes. Annealed goods lose their brittle character so that they can be bent without breaking. The fracture before being annealed is smooth and short; after that process it is rough, and exhibits bright parts of a crystalline appearance. Copper and brass suffer less from being annealed in an open fire than iron and steel: but a close vessel is necessary in order to preserve their metallic lustre. Very small brass wire is sometimes annealed by holding it in the flame of burning hay and straw.

Soft metals, such as tin, lead, and zinc, after being hardened by hammering may be softened by the action of boiling water. Most of the hard metallic alloys when made red hot, suffer no great change whether they be suddenly quenched in water or not. Pure hammered iron after annealing becomes equally soft whether it be cooled suddenly or slowly; but some inferior kinds of iron become hard by immersion in water. Steel receives by sudden cooling that extreme degree of hardness, combined with tenacity, which adapts it beyond every other material for cutting tools, especially as it admits of being regularly graduated from extreme hardness to the softest state when subsequently heated or tempered. The following are a few examples of the method of treating steel, so as to produce extreme hardness, and ending with the reverse condition. A thin heated blade worked between a cold hammer and anvil, or other good conductors of heat, becomes perfectly hard. A thicker piece of steel cooled by exposure to the air on the anvil becomes rather hard, but not too hard to be filed. When it is placed on cold cinders, or other bad conductor of heat, it becomes softer; but it becomes softer still when placed in hot cinders, or within the fire, and allowed to cool, by gradual extinction. When the steel is encased in close vessels with charcoal powder, and raised to a red heat, and allowed to cool in the furnace, it assumes its softest state; unless, indeed, it be made to undergo partial decomposition by enclosing it in a close vessel with iron turnings or filings, or with the scale from the smith's anvil, or with lime or other matters which attract carbon from its surface; this reduces it to the state of pure soft iron. Some descriptions of cast-iron may be made as hard as the hardest steel, forming what are called *chilled iron castings*. The reverse process is annealing with partial decomposition; this forms what is called *malleable iron castings*, and the process is so successful that cast-iron nails may be clenched. The purest iron, and most varieties of cast-iron may be superficially converted into steel by a process called CASE-HARDENING. For further particulars on this interesting subject we must refer to CUTLERY—GUN—IRON AND STEEL—METAL, &c.

The change which is produced by annealing is not well understood. Most of the malleable metals assume two distinct forms; one crystalline, which is the result of slow cooling, and the other fibrous, which is brought about by hammering or rolling. If hammered or rolled beyond a certain point, the metals become so hard that they cannot be bent without breaking. If annealed beyond a certain point the metals become crystalline. Thus, zinc may be drawn into a very flexible and tenacious wire, but if kept in boiling water too long it resumes its original brittleness, and displays a crystalline appearance when broken. The particles of the metal change their arrangement without altering the external form, and this change may be brought about in various ways; thus, brass wire loses its tenacity by exposure to the fumes of an acid, and even by air acting on its surface in a damp atmosphere. Hence it is necessary to preserve wire, such as is used in the manufacture of pins, in a dry air or under the surface of water.

ARNOTTO. ANNOTTA, a red colouring matter obtained from a plant (*Bixa orellana*), Fig. 49, common in the West Indies, where it is extensively cultivated on the banks of rivers, sometimes giving its name to the district, as *Annotta Bay*, on the northern coast of Jamaica. The arnotto plant is a small tree with deep-green, shining leaves, and clusters of purplish flowers. These are succeeded by bristly heart-shaped capsules, or seed-pods, containing numerous seeds covered with a soft, sticky rind of a bright red colour. It is a thick extract of this rind made into cakes and balls, which forms the arnotto of commerce. The cakes are usually of two or three pounds weight each, and are packed in casks with

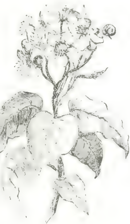

Fig. 49.

large flag leaves, hence the term *flag arnotto*. A superior kind, called *roll arnotto*, is a harder and more concentrated extract, of which but little is imported. The colour obtained from fresh pods of the plant is much superior to that of either of these preparations, leading to the conclusion that the method of preparing them, which is by a high degree of heat and fermentation, is injurious to the colour.

Arnotto dissolves entirely in water or milk, and is much used in colouring cheese and butter in England and Holland, the colouring matter being diffused in the milk previous to the manufacture. The Spaniards employ this substance in colouring and flavouring their chocolate and soups, esteeming it wholesome and stomachic. Dyers obtain from it the reddish colour called *aurora*. The liquid sold under the name of *Nankin dye* is a solution of arnotto in potassa, and pure water. A solution is also made in alcohol, and used in varnishing and lacquering. The Indians paint their persons with a mixture of arnotto, gum, and lemon-juice, as a preservative against the attacks of insects. Arnotto also has a fabulous reputation of being an antidote to the poison of the cassava root, which has fatal properties when raw, although, when cooked, it is a wholesome food. The consumption of arnotto in Great Britain has greatly increased of late years. In 1820, it amounted to but little more than 50,000lbs.: three or four times that quantity is now imported. The botanical position of the arnotto plant, is in a small group of tropical plants, called bixads, now included by Lindley in the natural order *Flacourtiaceæ*.

ANTHRACITE, [See Coal.]

ANTIMONY is a metal discovered by Basil Valentine, a monk of Erfurth, and an alchemist of the fifteenth century. It is related that having thrown some of it to the hogs it purged them violently, after which they became fat; and thinking that his brother monks might derive benefit from a similar dose, he administered it; but the effects were fatal, for the monks died; hence the medicine was called *anti-moine* or anti-monk. The ancients appear to have been acquainted with some of the compounds of this metal,[1] which Pliny names *stibium*, a word still used to express the metal, or in chemical symbols Sb. Its equivalent is 129.

Metallic antimony has a distinct platy, crystalline structure, and by particular management may be obtained in crystals which are rhombohedral; this metal has a bluish white colour, and a strong lustre; it is very brittle, and can be easily reduced to powder. Its specific gravity is 6.8. It melts at a temperature just short of redness, and boils and passes off in vapour at a white heat. It has a peculiar taste and smell, especially in the state of vapour. Antimony is not oxidized by the air at common temperatures; but when strongly heated it burns with a white flame, producing an oxide which often forms beautiful crystals. If a globule of antimony melted at the blow-pipe be thrown upon a sheet of paper or a board, it sparkles and bursts into a number of small spheroids, which remain hot for a considerable time, and move about the paper leaving traces of oxide behind them. There are three compounds of antimony and oxygen, viz., the oxide, antimonious, and antimonic acids. These acids combine with bases forming salts, which are distinguished as *antimonites* and *antimoniates*.

Antimony is dissolved by hot hydrochloric acid with evolution of hydrogen, and the production of a chloride formerly called *butter of antimony*, a substance sometimes used with sulphate of copper for bronzing gun-barrels, the iron decomposing the chloride, and depositing a thin film of antimony on its surface. Nitric acid oxidizes antimony into antimonic acid. Sulphuric acid has scarcely any action on it.

Antimony is found in many parts of Europe, but the mines of this metal are not numerous; it occurs native in Sweden, in France, and in the Hartz; but its principal ore is the sulphuret, which occurs massive and crystallized. There are several varieties, of which the most common is the radiated. This is of a grey colour, brittle, and frequently crystallized in four and six-sided prisms. The sulphuret is associated with quartz, sulphate of baryta, and carbonate of lime, from which it is separated by fusion; a method of purification analogous to the mechanical preparation of other ores, but on account of the great fusibility of the sulphuret of antimony this separation is accomplished by means of heat. For this purpose the ore is placed in large crucibles, C C, (Fig. 50,) perforated with a number of small holes in the bottom, and supported by tiles which are furnished with openings for admitting the perforated part of the crucibles. The fused matter is received into other crucibles, R R, placed in enclosed compartments. The upper crucibles are fitted with a

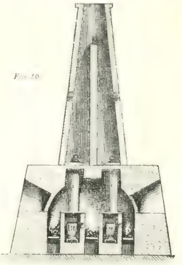

Fig. 50

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[1] The sulphuret was used by the ladies of Rome as a cosmetic for painting the eyebrows and the edges of the eyelids. The smoke black of a kind of resin, or of the shells of almonds, is now used for the purpose by females in the East.

cover, which is luted on, and a lute is also applied to the junction with the lower vessels. Heat from wood fuel is then applied, and after some hours firing the stony portion of the ore is left in the top crucibles, while the bottom ones contain the sulphuret which is known in commerce as *crude antimony*. In some works a small circular furnace is used for heating the crucibles which contain the ore, and the recipients being placed on the outside, the fused sulphuret flows into them by a channel which connects the two together. By this means the furnace can be worked constantly, whereas by the former method the cooling of both crucibles occasions a waste of fuel. The arrangement will be understood from Fig. 51.

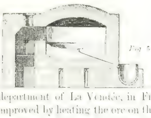
Fig. 51.

In the department of La Vendée, in France, this method is improved by heating the ore on the concave sole of a reverberatory furnace. This sole is formed of clay and charcoal, and communicates with a recipient outside by means of a channel, the upper extremity of which is stopped with ashes during the melting. The charge consists of 7 or 8 cwt. of the ore, and each tapping yields about 4 cwt. of crude antimony, which is about 50 per cent: in other places the yield is not more than from 30 to 40 per cent. Wood is the fuel employed.

When sulphuret of antimony is roasted in contact with the air, oxide of antimony is formed, which unites with that portion of the sulphuret which has not been decomposed. In this way several oxysulphurets are formed, which melt, and yield in cooling some brown vitreous substances, which are known in commerce as *glass of antimony*, *liver of antimony*, or *crocus*. Glass of antimony consists of 8 parts of oxide and 1 of sulphuret. It is transparent, and of a reddish yellow colour. Crocus contains 8 parts of oxide and 2 of sulphuret; it is opaque, and of a yellow-red colour. Liver of antimony is opaque, and of a deep brown colour; it consists of about 4 parts sulphuret and 8 parts oxide.

The reduction of the crude antimony to the metallic state is attended with some difficulty, for antimony is a metal sufficiently volatile to occasion great loss, but not volatile enough to pass over by distillation. The first process in the reduction is to roast the crude antimony at a very moderate heat, whereby, in 100 parts, 86 parts ought to be converted into protoxide, and the sulphur disengaged, to be converted into sulphurous acid; but in practice not more than about 60 or 65 parts of the protoxide are obtained. These 65 parts are next mixed with 8 or 10 parts of charcoal-powder, sprinkled with a strong solution of carbonate of soda. The mixture is placed in crucibles, and kept at a good red heat until the fusion is complete. By this process *regulus of antimony* is produced, while the scoriæ consist of a double sulphuret of antimony and sodium. The object of the carbonate of soda is to reduce a portion of the sulphuret of antimony by forming sulphuret of sodium, which combines with the remainder of the sulphuret of antimony in such a way as to cause it to collect in the scoriæ.

From the crucibles the metal is run into hot and greased moulds; but it is not as yet sufficiently pure to assume the crystalline form so much prized in commerce. It is remelted, with a portion of the scoriæ obtained in previous reductions, together with a certain proportion of the roasted mineral. The result of this second process is the production of an increased quantity of scoriæ and the purification of the metal.

Of the 65 parts of roasted sulphuret 45 parts of regulus are obtained in the first fusion, and this quantity is reduced to about 42 in the second; or, in other words, 100 parts of sulphuret of antimony, which ought to produce 73 of regulus, actually produce only 40 or 44. A portion is lost by volatilization, and another portion remains in the scoriæ. The scoriæ is known in commerce as *crocus* or *kermes*, and is used in veterinary medicine. It consists of sulphuret of antimony and alkaline sulphuret.

As iron combines readily with antimony, the sulphuret is sometimes reduced by heating it in contact with iron filings: as the iron tends to unite with the antimony, when in excess, an atom and a half of iron is employed to each atom of sulphuret of antimony, or 45 parts iron filings to 100 parts sulphuret of antimony.

M. Dumas states that many manufacturers keep their processes secret, which sufficiently accounts for the defective state of this branch of metallurgy; for, had they been thrown open to scientific chemists, they would have been investigated and improved.

In some smelting-houses there is a loss of regulus amounting to 33 per cent., and a much larger expenditure of fuel than is necessary. The secret consists in giving to the surface of the ingots a beautiful stellated appearance, which the alchemists formerly regarded as a mysterious guide to the secrets of transmutation, and which is now valued in commerce as an indication of superior purity in the metal. But it is well known that when pure antimony is cooled very slowly, in a still place, the crystallization is always very beautiful; and these conditions suffice to account for an appearance the importance of which is exaggerated by the manufacturer.

Antimony combines with the other metals, and renders them brittle; and, as this effect was especially remarked in the case of gold, the alchemists distinguished it by the title of *regulus*, or the little king, from its power of ruling over the noble metal, and destroying its malleability. The chief alloys of antimony are *type-metal*, consisting of 4 lead and 1 of antimony; *stereotype-metal*, 6 lead and 1 antimony; *music-plates*, consisting of lead, tin, and antimony; *Britannia-metal*, consisting of 100 parts tin, 8 antimony, 2 bismuth, and 2 copper. *Pewter* is sometimes formed of 12 parts tin and 1 part antimony. Antimony is also used in medicine, its two most important compounds being *antimonial powder* and *tartar-emetic*: the former, also called *James's powder*, is said to consist of 43 parts phosphate of lime and 57 oxide of antimony; the latter is a tartrate of potassa and antimony. Antimony is also used in the preparation of some enamels and other vitreous articles.

Great Britain receives the larger portion of its supply of antimony from Singapore, which receives it from Borneo. It is imported in the shape of ore, and commonly as ballast.

ANVIL. An instrument on which malleable metals are placed during the process of hammering. Anvils are sometimes made of cast-iron, but when required to be very hard or bright they are made of wrought iron and faced with steel. In such case the core or body is prepared at the forge, by welding together a number of rude blocks of iron. When the core is rudely shaped, three square holes are made in it, one in the bottom and one at each side, for the purpose of receiving a bar of iron connected with a crane near the forge, by which the anvil is held in the fire, and turned about while being forged. The common smith's anvil consists of seven pieces:—1, the core, or body; 2, 3, 4, 5, the four corners for enlarging the base; 6, the projecting end, containing a square hole for the reception of a set or chisel in cutting pieces of iron; and 7, the beak, or conical end, which is used for turning pieces of iron into a circular form, for welding hoops, &c. All these pieces are separately welded to the core. When the anvil is of large size two hearths are used, in one of which the core is raised to the welding heat and in the other the piece. They are then taken out and welded together by rapid hammering until they cohere. The whole is then heated again, and hammered until the proper shape is obtained.

The best anvils are faced with steel. This steel facing is shaped, heated, and laid on the anvil at a welding heat, the facing, however, being less heated than the anvil, and hammered rapidly until it is closely united: the whole is then finished by repeated heatings and hammerings. The anvil is next hardened by raising it, but especially the face, to a full red heat, and quenching it in a large quantity of cold water. It is of importance to cool it rapidly, and for this purpose a stream of water is to be preferred. In this process the steel facing will sometimes crack, unless it is thin. Should the hardening be successful, the facing is ground until it is perfectly even, and the edges are made sharp or round as required. When the anvil is to be used for planishing metals, it is polished with emery and crocus.

The smith's anvil is generally placed on a loose wooden block, such as the root end of an oak tree. Anvils used for cutting and for files are inserted into large blocks of stone. The more firmly the anvil is connected with the earth, the more effective is the blow of the hammer.

Locksmiths use a smaller kind of anvil called the *stake*, which is moveable, and is usually placed on the work-bench. It is used for setting small cold work straight, or for cutting or punching on with the cold chisel, or cold punch.

AQUA FORTIS. A common term, first applied by the alchemists to dilute NITRIC ACID, on account of its strong corrosive action on many animal, vegetable, and mineral substances.

AQUA REGIA. A term applied by the alchemists to a mixture of nitric and hydrochloric acids: it has the property of dissolving gold, which neither of the acids possesses separately. Two parts of hydrochloric and one of nitric acid are most effective. A partial decomposition of both acids takes place, and water, chlorine, and nitrous acid are the result. When a metal is placed in aqua regia it absorbs the chlorine, and is dissolved. This acid is the common solvent of gold and platinum.

AQUEDUCT, a conduit or channel for the conveyance of water, from the genitive case of *aqua*, water, and *ductus*, a conduit; hence the old method of spelling this word, *Aquæduct*, is more correct than the present. According to this derivation, any pipe or channel for the conveyance of water is an aqueduct; but the term is usually limited to those structures of masonry which are elevated above ground for the purpose of conveying a stream of water in a regular but slightly descending current across valleys and over plains.

An abundant supply of pure and wholesome water is essential to the health and prosperity of every town and city, and accordingly we find that in all ages and countries special provisions have been made to secure so desirable an object. The ruins of the aqueducts constructed in Palestine in the reign of Solomon still remain, and travellers describe the *Pools of Solomon* in connexion with a scheme for supplying Jerusalem with water. In the ruined cities of Central America, which still excite the astonishment of the traveller, the remains of aqueducts are also found; but of all the ancient aqueducts those of the Romans are most calculated to excite admiration, constructed as they were to pour into the city whole rivers of water for the use of the public baths, fish ponds, artificial lakes, gardens, villas, and private houses within and around the city. Some of these aqueducts extended thirty, forty, and even sixty miles from the city, in one continuous covered channel of stone, which was carried by means of arcades over the widest and deepest valleys, and by tunnels for miles through mountains and the solid rock. It is indeed a matter of painful regret that with our vastly increased engineering skill and improved means, the metropolis of a powerful nation like Great Britain should continue to languish and to suffer disease and misery, for want of an abundant supply of pure water.

Our knowledge of the aqueducts of ancient Rome is derived as well from repeated surveys of the stupendous ruins which still exist, as from a special treatise on the subject by Frontinus, who was curator of aqueducts under the Emperor Nero. We learn from this excellent authority,[1] that for about 400 years after the building of the city, water was supplied by the Tiber, or by wells and fountains; but as the population became greatly increased, the Censor, Appius Claudius, constructed an aqueduct for bringing in the water of distant springs. Other aqueducts were afterwards constructed as the wants of the city required, and it became a fashion with the great men of the time to present the city with the munificent gift of an aqueduct. In the time of Frontinus the city was supplied by nine large aqueducts; five more were added by Nerva, and the number was increased by successive emperors to twenty. They were mostly named after the rivers or lakes which supplied them, or after the emperors who caused them to be constructed. The *Virgin Aqueduct*, however, was so called from the circumstance of a young girl showing some veins of water to a few soldiers who were in search of a spring. On following these veins by digging, an abundant supply was procured, and, "there is a painting," says Frontinus, "in a little temple erected close by the source, representing the event."

The most remarkable aqueducts of ancient Rome were the *Aqua Appia*, the *Old* and the *New Anio*, the *Aqua Martia*, which also conveyed the waters of the *Aqua Julia* and the *Aqua Tepula*; the *Aqua Virginia* and the *Aqua Claudia*. The Aqua Appia was named in honour of the Censor, Appius Claudius, by whom it was constructed in the 442d year of Rome. Its source was in a field near the Via Prænestina, between the sixth and the eighth mile-stones: it made a circuit of 780 paces to the left, and then proceeded by a deep subterranean channel of more than eleven miles, and entered the city at the Appian way by the Porta Capena, and delivered the main body of its waters into the Campus Martius. The Old and New Anio conveyed to Rome the waters of that river. The former began above the Tiber at the 30th mile-stone, and consisted mostly of a winding channel of 43 miles. The latter took a higher level, running a length of 7,543 paces above ground, and then through a subterranean passage, a length of 54,267 paces. The Aqua Martia rose from a spring 33 miles from Rome; it made a circuit of 3 miles, and afterwards forming a vault of 16 feet diameter, ran 38 miles along a series of arcades at an elevation of 70 feet. Openings were perforated at certain places, for the discharge of the collected air, and at different parts of its course were deep cisterns, in which the water deposited its solid contents. The water of this aqueduct was celebrated for its clear green colour, and was praised by Pliny for its coolness and salubrity. The triple aqueduct of the Aqua Martia consisted of three stories or conduits, placed one above the other. The uppermost conduit was the Aqua Julia, the middle one the Aqua Tepula, and the lowest the Aqua Martia. This accounts for the extraordinary height of this aqueduct, and from the ruins of it which still remain it is called *Il castel del Acqua Marcia*. The Aqua Virginia was constructed by Agrippa: its source was a very copious spring, in the midst of a marsh 8 miles from the city, but its channel was about 12 miles, a portion of which was through a tunnel 800 paces in length. The Aqua Claudia was commenced by Nero and completed by Claudius; it rose 38 miles from Rome, and formed a subterranean stream of 36¼ miles, then ran 10¼ miles along the surface of the ground: it was vaulted for a space of 3 miles, and was supported on arcades through 7 miles, being carried along a level sufficiently high to supply all the hills of Rome. It was constructed of hewn stone, and of such excellent workmanship, that after withstanding the attacks of time during many centuries, and the still more destructive attacks of barbarians, it was found sufficiently perfect to be restored by Sixtus V., and it furnishes the modern city with water of the best quality. This aqueduct was named *Aqua Felice*, in honour of Sixtus V. whose conventual name was *Fra Felice*, or "Brother Felix."

It will be seen that in some of these aqueducts the length of the channel was greater than that of the roadway between the city and the source of the aqueduct. This was necessary to ensure a very gentle fall for the channel; for, if the source of the water conveyed were much higher than where it was to be delivered, the pressure of water from the head would burst or blow up the covering arch or coping of the aqueduct, and thereby render the structure useless, and inundate the district over which it was attempted to convey it. Hence in order to reduce the flow of water to the proper velocity, the stream had frequently to be carried in a winding direction so as to extend the height in a greater length. In all these aqueducts the whole channel was regularly built of stone or

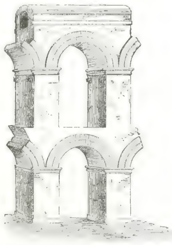

Fig. 2.

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[1] An excellent edition of this author is that published by Rondelet, with the Latin text on one side and a French translation on the opposite page. It is entitled, "Commentaire de S. J. Frontin sur les Aqueducs de Rome. Par J. Rondelet," Paris 1820. The work is accompanied by an Atlas of 31 large copper plates. The reader who desires further information, should also consult Fabrettus, "De Aquis et Aquæductibus veteris Romæ." [illegible]

brick, and arched above to cover in the channel, so as to protect the water from impurities and evaporation. In crossing valleys the conduit was raised upon a series of arches with massive piers and of solid substantial structure, sometimes of brick, and often of hewn stone. When the height was not very great a single row of arches sufficed, but in other cases a double row was constructed as in Fig. 52. Many of these works exceed in magnitude even those portions of our modern railroads which have been the admiration of our age. The aqueduct of New Anio, for example, consisted during $6\frac{1}{2}$ miles of one continuous series of arches, many of which were upwards of 100 feet high. In the 38 miles which formed the length of the Aqua Martia, there were nearly 7,000 arches. The New Anio conduit was 63 miles 700 paces in length, of which 49 miles 200 paces formed a subterranean stream; in 9 miles 400 paces the conduit was above ground, and some of the arches 109 feet.

The following table represents the supply of water to Rome from the nine earlier aqueducts. It has been constructed from the data furnished by Frontinus:—

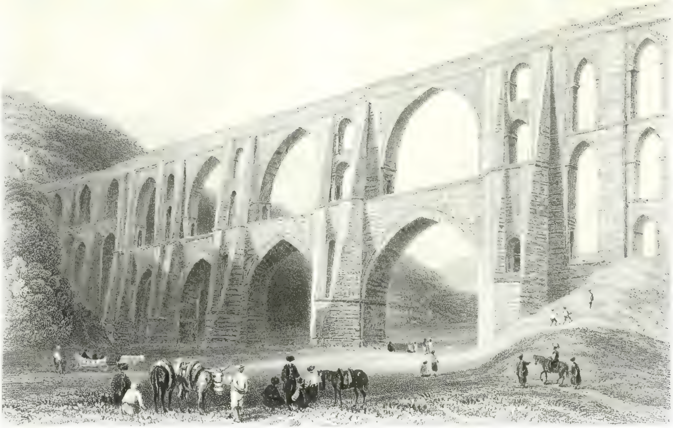
Name of the Aqueduct.		Era of its construction.	Length in miles.	Cubic feet of water discharged in 24 hours.	Gallons in Wine Measure.
1 Appian Aqueduct ...	B.C.	312	10·2250	3,706,575	27,724,181
2 Old Anio ...	,,	273	[illegible]·0775	8,932,338	66,813,887
3 Marcian ...	,,	144	56·9417	9,[illegible]	71,249,947
4. Tepulan ...	,,	127	11·2741	[illegible]	6,760,35[illegible]
5. Julian ...	,,	35		2,44[illegible]86	18,321,407
6 Virgin ...	,,	22	14·2115	5,08[illegible]624	38,040,167
7 Alsietina ...	A.D.	14	[illegible]	796,152	5,[illegible]5,016
8. Claudian ...	,,	49	42·1[illegible]	[illegible]817	96[illegible]1
9. New Anio ...	,,	90	[illegible]	9,622,873	71,[illegible]
			249·[illegible]	[illegible]	270,[illegible]

Some auxiliary supplies or feeders make the total length of the Roman aqueducts to exceed 255 miles.

Modern Rome is also abundantly supplied with water, either by means of new aqueducts, or by the ancient structures which have been repaired.

In the cities of the provinces of the vast Roman Empire were conduits and aqueducts on as large a scale as those which supplied the capital of the empire, and in some cases larger. Our limited space will not allow us to notice more than one of these, viz. the Aqueduct of Nismes, which is, perhaps, the most remarkable Roman remain of the kind, surpassing even the aqueducts of Rome in lightness and striking boldness of design. That portion of the aqueduct which crosses the river Gardon, and hence called the *Pont du Gard*, (Fig. 53,) is thus noticed in Murray's *Hand-Book for Travellers in France*: "The sight of this noble edifice, one of the grandest monuments which the Romans have left behind them in France or any other country, would well repay for a very long detour. Like Stonehenge, it is the monument of a people's greatness, a standard by which to measure their power and intellect. It consists of 3 rows of arches, raised one above the other, each smaller than the one below it; the lowest of 6 arches, the central tier of 11, and the uppermost of 35; the whole in a simple, if not stern style of architecture, destitute of ornament. It is by its magnitude and the skilful fitting of its enormous blocks that it makes an impression upon the mind. It is the more striking from the utter solitude in which it stands, a rocky valley, partly covered with brushwood and greensward, with scarcely a human habitation in sight, only a few goats browsing. After the lapse of sixteen centuries, this colossal monument still spans the valley, joining hill to hill, in a nearly perfect state, only the upper part at the north extremity being broken away. The highest range of arches carries a small canal about 5 feet high and 2 feet wide, shaped like the letter U, just large enough for a man to creep through, still retaining a thick lining of Roman cement. It is covered with stone slabs, along which it is possible to walk from one end to the other, and to overlook the valley of the Gardon. The arches of the middle tier are formed of 3 distinct ribs or bands, apparently unconnected. The height of the Pont du Gard is 180 feet, and the length of the highest arcade 873 feet. Its use was to convey to the town of Nismes the water of two springs 25 miles distant, the Airan rising near St. Quentin, and the Ure near Uzès. It forms only a small portion of the conduit constructed for this purpose, whose course, partly raised on low arches, some of which exist on the north of the Pont du Gard, partly cut in the rock round the shoulders of the hills, may be traced at the village of St. Maximin near Uzès, and above that of Vers, to the Pont du Gard; thence, by St. Bonnet and Sernhac, to the hill of the Tour Magne and Bassin des Thermes at Nismes. The conveyance of this small stream was the sole object and use of this gigantic structure, an end which would now be attained by a few iron water-pipes. Its date and builder are alike lost in oblivion, but it is attributed to M. Agrippa, son-in-law of Augustus, B.C. 19. The quarry whence the stone was obtained is a little way down the Gardon, on its left bank. The bridge by which the road crosses the Gardon on a level with the lower tier of arches, and formed by merely widening them, is a modern addition to the ancient structure, having been erected in 1743 by the States of Languedoc."

The Pont du Gard above described occupied about a medium position in the acqueduct, which was nearly 30 miles in length, forming in its course the figure of a horse-shoe. The channel way was of stone throughout. The bottom of the interior had a curved form, being an arc of a circle; the sides were vertical, and the top was covered with a flagging of cut stone, except where the channel ran underground, in which case it was covered by an arch of stone. The interior face of the walls and bottom of the conduit was covered with a coating of plaster 2 inches thick, composed of quick lime, fine sand and brick nearly pulverized. This coating has now a tenacity equal to the hardest stone. The size of the channel way is 4 feet wide, and $5\frac{1}{3}$ feet high, except where it was covered by an arch, in which case it was $7\frac{1}{2}$ feet high in interior dimensions. The descent was 1 foot in 2,500, or $2\frac{11}{100}$ feet per mile. The water formed a deposit of lime on the sides of the



channel, until nearly half the channel was closed, this deposit being 11 inches thick on each side. This aqueduct appears to have been in use for more than 4 centuries, and now, after the lapse of 14 centuries, it is in such good preservation that it could be restored without any very considerable outlay.

In modern times the French have imitated the Romans in the construction of aqueducts. The aqueduct for conveying water from Versailles to Marli was built by Louis XIV. at great expense. The famous aqueduct bridge of Maintenon was erected for conveying the waters of the river Eure to Versailles. This magnificent structure is 4,400 feet in length, or nearly $\frac{7}{8}$ of a mile, and is upwards of 200 feet high; it consists of 242 arcades, each divided into 3 rows, making in all 726 arches of about 50 feet span.

It is frequently stated, that had the Romans been aware of the principle that water seeks the level of its source after encountering depressions in its conduit, they might have spared themselves the immense labour and cost of constructing their colossal aqueducts, by forming an inverted syphon of pipes across valleys. It might as reasonably be argued that the modern French and Americans were ignorant of this principle, because they have preferred the stone conduit to the system of pipes. The fact is, that the Romans were fully aware of the principle in question, as is proved by the remains of many of their works, but they preferred a system of stone channels, not only on account of the greater permanence and durability of the work, but also on account of the greater abundance of the supply of water which this method secured, and its greater purity. In considering the best method of supplying the city of New York with water from the Croton river, situated at a distance of 38 miles from that city, it was calculated that a system of iron pipes would be more costly than an enclosed stone channel, and far less durable. An open canal was also objectionable on account of the loss of water by filtration through the banks, and by evaporation. Another objection to the open canal was the difficulty of preserving the water from receiving the wash of the country through which it passed, and of preventing injurious matters from being thrown into it and rendering it impure; impurities might also be contracted in passing through different earths; frost would also interfere with the supply. When we find an enterprising and intelligent nation like the Americans adopting the system of the ancient Romans, it is difficult to suppose that the same reasons did not in both cases lead to the adoption of the same method. When the system of sewage and water supply of modern London shall exceed that of ancient Rome, we shall then, and not till then, be in a condition to accuse the old masters of the world of ignorance.

In the magnitude of our metal castings for pipes, the moderns are certainly superior to the ancients, and in some cases a system of iron pipes has been used to supply a city with water. Such is the case at Edinburgh, which is supplied by the Crawley Spring from the rising ground on the south base of one of the Pentland Hills. The distance is scarcely 7 miles from Edinburgh in a straight line, but it is $8\frac{3}{4}$ miles by the line of pipes. The spring is 564 feet above the level of the sea, and 360 feet above the level of the reservoir in Princes Street. The original issue of the spring is augmented by a drain carried about half a mile above the spring, up the valley in which the spring is situated. The soil of the valley is of gravel 40 feet deep, forming a vast natural filter, through which the water from the high grounds on each side percolates. The water is thus rendered very pure, and being all intercepted by the drain, is conducted with the original discharge of the spring into a reservoir or water-house, from which the pipes take their rise, and continue in one connected train to the city. For the first 3 miles the pipes are from 18 to 20 inches in diameter, and afterwards 15 inches. As they approach the city they are carried through a tunnel under Heriot's Green, and another under the Castle Hill through the solid rock. By means of a reservoir, branch-pipes and service-pipes, the water is supplied to each house or floor of a house. Air-cocks are placed at intervals all along the main pipes, to let off the accumulated air, which is done by hand every three or four days. The average supply of water by this aqueduct is 180 or 200 cubic feet per minute, and it is stated that double this quantity could be easily supplied. The water is said to be of the finest quality; it issues from a deep source and at a great altitude, so that it is fresh and cool even in the heat of summer. In this respect the supply of Edinburgh is far superior to that of most other towns of the same magnitude. The elevated nature of the country about the city affords facilities for distributing the water without the aid of machinery.

Aqueduct bridges were first used in this country for the canals constructed by the Duke of Bridgewater, under the direction of Brindley. The first and largest was the aqueduct at Barton Bridge, for conveying the canal across the Irwell, 39 feet above the surface of the river. It consists of three arches, the middle one 63 feet span, admitting under it the largest barges which navigate the Irwell, with sails set. This aqueduct bridge was commenced in September 1760, and in the July of the following year, the singular spectacle was first seen in this country of vessels sailing across the course of the river, while others in the river itself were passing under them. So little were engineers acquainted with works of this kind at the time of its erection, that when, at the request of Brindley, an eminent engineer was called in to give his opinion respecting the proposed aqueduct, he said with a sneer, "I have often heard of castles in the air, but never before was shown where any one of them was to be erected."

Allusion has been already made to the construction of aqueducts on a large scale in the United States of America, by improving on the model of the ancient Romans. New York had always been badly supplied with fresh water: the quantity collected, chiefly from wells, was small and the quality bad. So long back as the year 1798, Dr. Brown, in an official report, considered these as the chief causes of the yellow fever and other contagious diseases which so frequently ravaged the city. He shows that the well-water, although cool and pleasant to the taste by the admixture of carbonic acid, was nevertheless contaminated with the filth of men and animals, which sinks into the streets, yards and stables, and then drains through the cemeteries, before it reached the collecting pond. The water was so bad that the ships in the harbour could not use it at all, but brought their supply from other seaports. At length the citizens became fully impressed with the necessity of obtaining a plentiful supply of pure water, by the ravages of the yellow fever in the summer of 1822, and of the cholera in 1832. After some preliminary proceedings, an Act was passed in May 1834, appointing five Water Commissioners, with powers to examine and consider all matters relative to the supply of the city of New York with a sufficient quantity of pure and wholesome water, and to adopt such plans as in their opinion would be most advisable for securing such supply. After much careful inquiry it was decided that the Croton river was the only source that could be depended on for present and future purposes, to ensure a sufficient quantity at all seasons at an elevation precluding the use of steam or other extraneous power, and that the quality of the water was unexceptionable. The distance of the Croton river from New York is about 40 miles, over a country extremely broken and uneven, and following a direction for a part of this distance parallel with the Hudson river, and encountering the streams which empty into it and form deep valleys in their courses. To convey this water to the city, it was decided to erect a close channel or conduit of masonry.

[illegible] AQUEDUCT OF NISMES, [illegible] THE PONT DU GARD. See page [illegible]2.

The sources of the Croton are principally in the county of Putnam, fifty miles from New York; they consist mostly of springs, which in that elevated and uneven country have formed many ponds and lakes never failing in their supply. About 20 of these lakes form the sources of the Croton river, and the magnitude of their surface areas is about 3,800 acres. The country is sufficiently cleared to prevent any injury to the water from the decay of vegetable matter. The river has a rapid descent, and flows over a bed of gravel and masses of broken rock, and the water is so pure that in earlier days the native Indian called it "the Clear Water."

Having ascertained the elevation in the city at which it would be desirable to distribute the water, it was only necessary then to find a point on the Croton river where a dam could be constructed, so as to turn the water into a channel gradually descending from this point through the whole length of the aqueduct to the required elevation in the city. At the spot where it was decided to construct the dam across the Croton river, the surface of the natural flow of water was about 58 feet below the elevation required as a head from which the water was to flow into the channel of the aqueduct. By going farther up, a dam of less height would have sufficed, but in that case some important tributaries of the Croton would have been lost. The medium flow of water in the Croton, where the Fountain Reservoir was formed, exceeds 50,000,000 gallons in 24 hours, and the minimum flow after long droughts is about 27,000,000 within the same period. The dam sets the fountain back about 6 miles, thus forming the Fountain Reservoir, which covers an area of about 400 acres, forming a beautiful sheet of water in the lap of the hills, in the wild region of the Croton. It has received the name of the "Croton Lake." The country forming the valley of the river was such as to give in general bold shores to this reservoir, and in cases where there was a gentle slope or level of ground near the surface of the water, excavations were made so that the water should not be of less depth than 4½ feet. In this reservoir the water collects and settles before it flows into the aqueduct. The available capacity of this reservoir down to the level at which the water would cease to flow off into the aqueduct, is estimated at 600,000,000 gallons; so that if the number of inhabitants of New York be estimated at one third of a million, the Fountain Reservoir would contain a supply for 90 days in a season of extreme drought; in addition to which, the Reservoir in the city would afford a further supply of about 25 days, thus providing for a season of 4 months' drought. Should the population greatly increase, other streams can be turned into the upper branches of the Croton, or into the aqueduct along its course. Other reservoirs might also be constructed further up the Croton, to draw from in time of need.

From the Fountain Reservoir on the Croton to the Receiving Reservoir on the Island of New York, a distance of 38 miles, no essential change was made in the form of the channel way, except in crossing Harlem river to reach the island, and also in passing a deep valley on the island, in both which cases iron pipes were used instead of the channel way of masonry. At these points the iron pipes descended and rose again, so that when water is flowing in the channel they are completely full. The channel way of masonry is never filled entirely, so as to occasion a pressure on its interior surface. To prevent this, 6 waste weirs were constructed at suitable places, to discharge the surplus water: they were formed on one side of the channel way, so as to allow the water to flow off when it rose above a certain level.

The following figures will show the kind of work employed in constructing the channel. Fig. 54 is a section of the aqueduct, showing the form of masonry used in earth excavations. The foundation was formed with concrete, the side walls are of stone, and the bottom and sides of the interior faced with brick, and the top covered with an arch of brick. After the masonry was finished, the excavation was filled up around it, and over the top of the roofing arch, generally to the height of 3 or 4 feet, and in some cases of deep excavation up to the natural surface.

Fig. 54.

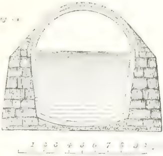


Fig. 55 is a section of the aqueduct in open cuttings in rock. The rock was excavated to the required depth and width; the bottom was levelled up with concrete to the proper height and form for receiving an inverted arch of brick; the side walls were of stone and brick bonded together, and built closely against the sides of the rock and forming a junction with it. On the exterior of the roofing arch, a heavy spandril of stone masonry was built, filling the space between the arch and the rock. After the masonry was finished, the excavation above it was filled with earth.

Fig. 55.

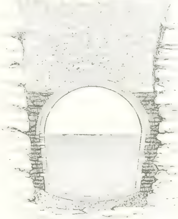


Fig. 56.

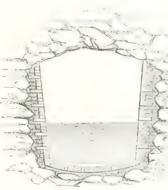


Fig. 56 is a section of the aqueduct in rock tunnel cuttings. The natural rock often served as a roof for the channel way where the rock was sound, but where soft a brick arch was built over the channel way, and the space between its extrados or outer surface was filled with earth closely rammed around it. In some instances, where the perforated rock was at first quite hard, the natural roofing became, by exposure to the air, soft and insecure, so as to render it necessary to turn an arch for its support; a difficult operation after the tunnel had once been formed.

Fig. 57 is a section of the aqueduct in earth tunnel cutting. When the earth was dry and compact, the excavation for the bottom and sides was made of the proper form to receive the masonry built closely against it. The top of the excavation was made sufficiently high to give room to turn the arch, and the space above was filled with earth closely rammed in. Where the earth was wet, the excavation was made larger, and props of timber and plank were used to support the top and sides until the masonry was completed; the whole exterior space was then compactly filled with earth.

Fig. 57.

In carrying the aqueduct across valleys, it was supported on a foundation wall of stone laid dry, and sloping embankments of earth were then constructed on each side.

Over the aqueduct were erected ventilating shafts of stone, rising about 14 feet above the ground. One of these was erected every mile, and every third shaft was furnished with a door to afford entrance to the aqueduct for the purposes of inspection and repairs. Openings 2 feet square were also made in the top of the roofing arch every quarter of a mile. Each opening was covered with a flag-stone, and the spot marked by a small stone monument projecting above the surface. The object of these openings is to obtain entrance or to increase the ventilation if necessary.

In places where streams intersect the line of aqueduct, culverts or stone channel ways were erected, to allow the water to pass under, and to pursue its natural course without injury to the work.

At the head of the aqueduct is a tunnel and a gate-chamber in connexion with the Fountain Reservoir, as shown in the longitudinal section, Fig. 58. This gate-chamber is not connected with the dam itself, but stands at some distance from it, and the water reaches it by means of the tunnel, T, which leaves the reservoir, S R, above the dam, and passes through the solid rock of the hill against which the masonry is built, a distance of upwards of 200 feet. This tunnel descends into the Reservoir, so that the centre of it at the mouth is about 12 feet below the surface of the water. This prevents floating substances from entering it, and during winter, when the water is frozen over, there is no obstruction to the flow into the aqueduct, A, and during summer the water is drawn from a level where it is cooler than at the surface.

The gate-chamber has two ranges or sets of gates; one set called *regulating gates*, R G, and the other *guard gates*, G G. The regulating gates are made of gun-metal, and work in frames of the same material, which are fitted to stone jambs and lintels; the guard gates are of cast-iron, and work in cast-iron frames; also attached to stone jambs and lintels. The gates are managed by means of wrought-iron rods attached to them, having a screw formed on the upper part on which a brass nut works, being set in a cast-iron socket cap.

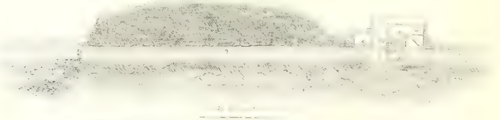


Fig. 58.—Section of the Tunnel and Gate-chamber of the Croton Aqueduct.

The accompanying view, Fig. 59, is taken above the dam, showing the position of the entrance to the tunnel leading from the reservoir to the gate-chamber. The entablature on the left against the rock is built directly over the mouth of the tunnel, and from this the tunnel extends through the rock to the gate-house seen on the right of the view, and at some distance from the dam. In the centre, on the ridge of the dam, is a gate-house over a culvert which extends through the body of the dam. This culvert is 30 feet below the surface of the water when the reservoir is full, and has gates opening by rods rising into the house. When the river is low, the water which is not drawn off by the aqueduct can pass through this culvert, and allow none to pass over the dam.

The bottom of the water-way of the aqueduct, where it leaves the gate-chamber, is 11.49 feet below the surface of the Fountain Reservoir, and 154.77 feet above the level of mean tide at the city of New York. The length of the aqueduct as it is divided into different planes of descent, from the gate-chamber at the Croton Dam to the gate-chamber at the Receiving House on the Island of New York, is as follows:—

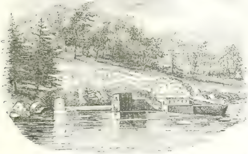


Fig. 59. THE CROTON LAKE AND DAM.

	Feet.	Miles.		Feet.
The first plane of aqueduct extends	26,0[illegible]72	or 4.943,	and the descent	[illegible]
The second ditto	118,121.25	,, [illegible]	,,	[illegible]
Length of pipes across the Harlem River	1,377.33	,, 0.261		
Difference of level between the extremes of pipes	......	......	,,	[illegible]
The third plane of aqueduct extends	1[illegible]11	,, [illegible]	,,	[illegible]
Length of pipes across the Manhattan Valley	[illegible]	,, 0.777		
Difference of level between the extremes of pipes	......	......	,,	[illegible]
The fourth plane of aqueduct extends	[illegible]	,, [illegible]	,,	[illegible]
	[illegible]117.[illegible]	[illegible]		[illegible]

The descent on the first plane is about 7½ inches per mile; on the second and third planes about 13¼ inches per mile; and on the fourth plane about 9½ inches per mile.

The bottom of the water-way of the aqueduct at the gate-chamber, where it enters the receiving reservoir, is 7.86 feet below the level of the top water-line in the reservoir; so that when the reservoir is full, the water will rise to within 7¼ inches of the top of the interior of the aqueduct at that place, and the height from the top water to the top of the interior will increase according to the plane of the aqueduct grade, until it reach the surface level of the flow of water in the aqueduct.

The height of the interior of the aqueduct is 8 feet 5½ inches, and the greatest width is 7 feet 5 inches. The sectional area of the interior is 53.34 square feet. On the first plane the aqueduct is larger, being 2.05 feet higher at the gate-chamber, 2.31 feet higher at 2,244 feet from the chamber, and diminishing to the head of the second plane, where it is of the dimensions above mentioned, and continues the same throughout, except in tunnels, where the dimensions are those already stated.

The curves used to change the direction of the line of the aqueduct are generally formed with a radius of 500 feet; some have a radius of 1,000 feet; and in a few instances even larger ones have been adopted.

The velocity of the water in the aqueduct is about a mile and a half per hour, when it is 2 feet deep. This was determined by floating billets of wood from the Croton Dam to Harlem River, and noting the time of their passage. This would give the surface velocity, which is greater than that of the whole body of water in the aqueduct; but, as the working depth is 4 feet, there is a corresponding increase in the velocity of the body of water: hence, the velocity of a mile and a half an hour may be taken in general terms as the velocity of the water in the aqueduct.

The Receiving Reservoir, into which the aqueduct discharges its water, occupies an elevated part of the island of New York. It is 1,826 feet long, and 836 feet wide, from outside to outside, at the top of the external walls of the embankment, making altogether an area of 35 acres. In this, as in almost every instance of excavation, the rock was found above the proposed bottom of the excavation; and the difficulties of preventing leakage along the surface of the rock were great. The natural veins and fissures of this gneiss formation, and the partial unsoundness of the rock, rendered leakages still more probable; but all this was overcome by the skill of the engineers. The embankments of the reservoir were made of good assorted earth, and a portion of the bank was puddled, or made compact and impervious by wetting the earth and using a spade to force it into a compact state. The embankments were about 20 feet wide on the top, and increased in thickness towards the base by sloping on both sides. The outside face was protected by a stone wall, 4 feet thick, with the face laid in mortar; the inside face was protected by a sloping wall of stone, 1¼ feet thick, laid without mortar. The top of the bank is 4 feet above the top water-line, and the inside sloping wall terminates 2 feet above the top water-line, leaving the remainder of the face to be covered with grass, so as to present a belt of green above the water on the bank all round the reservoir. A neat fence bounds the outside and the inside of the top bank, forming a walk of a mile in length round the entire reservoir. The reservoir is formed into distinct divisions: the greatest depth of the water in the north division is 20 feet, and in the south division 30 feet; but the whole of the rock to these depths was not excavated. The capacity of the reservoir, when both divisions are full, is 150,000,000 imperial gallons. The aqueduct enters a gate-chamber in the south division, where there are regulating gates for discharging the water into either division by a continuation of the aqueduct within the reservoir. There is also a connexion-pipe of cast-iron, for allowing the water to flow from one division into the other, so as to equalize the level. There is also a waste-weir for draining off the surplus water into a sewer. Mr. Towers remarks truly, that this beautiful lake of pure water resting on the summit of the island is truly a pleasing object, and, considering its size, is what no other city can boast of having within its limits.

From the Receiving Reservoir the water flows, by means of large pipes, a distance of two miles, into the Distributing Reservoir, situated within the city, the object being to have a sufficient head of water near the densely-populated parts. Fig. 60 is an isometrical view of this reservoir. The pipes from the Receiving Reservoir enter it at the base of the central pilaster. The flow of water is regulated by stop-cocks; and a door in the pilaster affords an entrance to the vault in which the stop-cocks are situated. This reservoir is divided into two parts by means of a wall. On the south side of the reservoir a pipe, 3 feet in diameter, proceeds from each division to the supply pipes, so arranged as to draw from one or both divisions. The house standing across the dividing wall is situated directly over the mouth of the effluent pipes, which leave the reservoir at the base of this pilaster. The water is distributed over the town, through 134 miles of pipe, of all sizes, between 36 and 4 inches bore. By this means also several public and private fountains are supplied. Feed-pipes, from half-an-inch to 1 inch bore, are led from the main-pipes into the basement of every house, and in many cases a pipe rises to the bed-rooms, for supplying baths, &c. The mains are also furnished with muzzles, to which the engine-hose of fire-engines can be screwed, for extinguishing fires; and at the harbour pipes are branched out, terminating at the bulwarks, for supplying ships, and filling the water-casks on board, by means of a hose. The Distributing Reservoir is 425 feet square, measuring from the top of the corners of the main wall, and 436 feet square at the base. It covers a little more than 4 acres. Its height is 45 feet above the neighbouring streets, and about 50 feet above the foundations. Its capacity is 20,000,000 gallons. The outside walls are constructed with openings in them, so that by entering a door one may walk entirely round the reservoir, within the walls. The object of this construction was to obtain a greater breadth with a given quantity of material, and also to afford an opportunity of examining the work, so as to guard against leakages, and to prevent any moisture from finding its way through the exterior, so as to cause injury to the wall by freezing. This kind of open-work rises to within about 8 feet of the top of the water-line. Inside these walls is an embankment of puddled work, formed with a suitable breadth of base to give security to the work, and the face of this embankment next the water is covered with a wall of hydraulic masonry $1\frac{1}{4}$ foot thick. The top of the embankment is covered with a stone flagging, forming a walk round the reservoir, and is bounded by an iron railing. The exterior of the reservoir is built on a slope of one-sixth its height, and an Egyptian cornice projects at the top of the main wall and pilasters. Terraces are formed at the foot of the walls, covered with grass, giving a rich finish to the work.

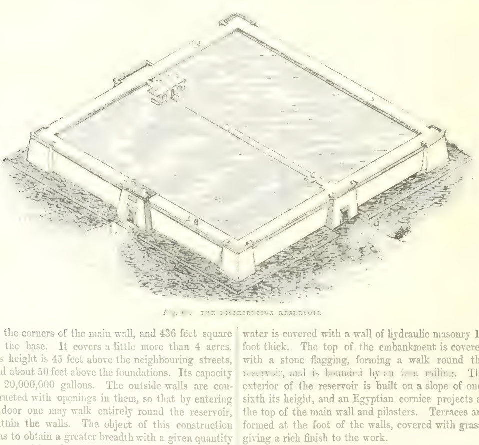


Fig. 60. THE DISTRIBUTING RESERVOIR.

This reservoir may be considered as the termination of the Croton Aqueduct. Its distance from the Fountain Reservoir on the Croton River is $40\frac{1}{2}$ miles. The cost of this noble work amounted to 8,575,000 dollars, including the purchase of land and extinguishing water rights and some unfinished works. This amount is within 5 per cent. of the estimate of the chief engineer, Mr. John B. Jervis. To this sum must be added 1,800,000 dollars, as the cost of the distributing pipes. The first two millions were raised at interest of 7 per cent., and is payable from 1847 to 1857 : 5 per cent. interest was charged for the remainder, to be redeemed from 1858 to 1880. A discount of 647,157 dollars was charged for issuing the loan, which, together with the interest paid during the construction of the work, brings the total expense to 12,500,000 dollars. The annual interest for this capital amounts to 665,000 dollars, which is raised by a direct water-tax and some indirect taxes. By means of an existing sinking-fund the capital will be gradually redeemed. The water-tax amounts to 10 dollars for a house of middle size, and there are more than 33,500 houses in the city. Manufactories, hotels, bathing houses, distilleries, livery-stables, breweries, slaughter-houses, &c., and ships, pay according to the rate of consumption.

The complete success of the Croton Aqueduct has stimulated other cities of the United States to adopt similar plans for obtaining a supply of pure water. The Boston Aqueduct is a worthy successor of the Croton.

Our chief authority for the details respecting the Croton Aqueduct is an excellent work, entitled, "Illustrations of the Croton Aqueduct," by F. B. Towers, of the Engineer Department; New York and London, 1843. We have also consulted Schramke's "Description of the New York Croton Aqueduct."

ARCH. See Bridge.

ARCHIL. Orchil. Cudbear. A violet dye obtained from several species of lichen, the most important of which are *Roccella tinctoria* and *fusiformis*, the dye of which makes litmus, and is largely used by manufacturers under the name of Archil or Orseille des Canaries, and *Lecanora perella* or *Orseille de terre*, and *L. tartarea* or Cudbear. Other species may be similarly employed, and the mode of testing is as follows :—The lichen whose properties are to be ascertained is placed in a glass bottle, and moistened with equal parts of ammonia and lime-water. A little hydrochlorate of ammonia is also added, and the bottle corked. In three or four days the small portion of liquid which will run off on inclining the bottle, will perhaps be tinged with crimson, and the plant itself will assume the same colour. If so, the lichen will yield a dye similar to that of Roccella tinctoria. The last named lichen or Archil plant is abundant in the Canaries and Cape Verd islands, and in the Levant. Pliny describes it as growing on the rocks of Candia and Crete, and says that the first tint or ground colour of the costly purple was given with the dye obtained from this plant. So in the present day, archil is chiefly used to improve other colours, and give richness and brilliancy to them, being too fleeting to be employed alone. The use of this dye was revived in Italy in the fourteenth century by a Florentine, who enriched himself and his country by making it a branch of commerce. The Spanish name of the lichen was Orciglia, and this became Oricella or Orchella, and the family who had revived the manufacture Oricellarii, afterwards corrupted into Rucellai and Ruccellai, a name still found among the first families in Florence.

This lichen has an upright growth of about two inches, and when old is crowned by flat, round disks. The colour varies from white to dark grey. The several lichens employed in this dye are largely exported from the places where they grow, and are in considerable request at the ports of London, Amsterdam, and Marseilles. One hundred and thirty tons of the Lecanora tartarea are annually exported from Sweden. These lichens are principally collected on the rocks near the sea, and are frequently packed without any previous preparation. But it is necessary before using them, to clear and grind them into a pulp with water. Ammoniacal liquors derived from gas-works, or occasionally from urine, are gradually added, and the mass is frequently stirred so as to expose it to the action of the air. The colouring matter is thus evolved, and is afterwards pressed out and made into a paste with chalk and plaster of Paris. This is the archil of commerce.

Archil readily yields its colouring matter to both water and alcohol. A total exclusion of air from this substance destroys its colour as effectually as too much exposure. Thus in spirit thermometers in which the liquid is usually tinged with archil, if the exclusion of air is complete, the colour gradually fades away, but upon breaking the tube, the colourless spirit soon resumes its colour, and this fading and reviving may be carried on a number of times in succession.

One of the principal sources of colouring matter in lichens is a chemical substance called *orcine*, which reddens on exposure to the air. Orcine has a sweet but somewhat repulsive taste; its properties are perfectly neutral; it crystallizes in flat four-sided prisms.

In the dyeing of silks archil is frequently employed for lilac colours, hence their usually fleeting character; but with other hues this dye is merely used to modify or brighten, the silks being passed through a bath of archil to receive the peculiar bloom of that substance. The beauty imparted by this dye is a temptation to manufacturers to employ it too largely. Archil is employed with indigo in the woollen cloth manufacture, and produces a saving of indigo, while it gives a rich appearance to the blue or black cloth dyed with it, but this requires caution, and the bloom imparted is often deceptive. Archil cannot be made more durable by the ordinary means; a solution of tin appears to be the only substance capable of fixing it, and this changes the colour from violet to crimson.

A fine violet colour is imparted to marble by archil, and this is less fugitive than other forms of this dye.

The preparation called *Cudbear*, (Cuthbert,) is so named from Dr. Cuthbert Gordon, who took out a patent for this mode of preparation, and connected it with his own name.

ARCHIMEDEAN SCREW. See Screw.

AREOMETER. A kind of hydrometer. See Gravity, Specific.

ARGAND LAMP. This valuable invention has been named in honour of the inventor Ami Argand, a native of France, who in 1789 contrived a burner consisting of two metallic cylinders one within the other, the annular space between them, which is closed at the bottom, containing oil and a cylindrical wick, the latter being attached to a short brass holder which is regulated by a screw. The space within the inner metallic cylinder is open both at top and bottom. When the wick is lighted it burns with a dull, wavy, smoky flame, but on suspending over it, as Argand did, a cylinder or chimney of sheet-iron, a powerful draught is excited both within and without the ring of flame, and the additional quantity of air thus brought into contact with the flame, greatly improves its brilliancy by ensuring the perfect combustion of the carbon, which without such a contrivance passes off in smoke. Soon after the original invention, Lange suggested a glass instead of an iron chimney, and altered its form by contracting the diameter of the cylinder a little above the burner. By this means the draught on entering the cylinder has its direction changed at the point where the contraction begins, and is thus thrown upon the flame in a more advantageous direction for combustion. [See GAS LIGHTING—LAMP.]

ARRIS, the intersection or line, on which two surfaces of a body forming an exterior angle meet each other. The term is used by all workmen employed in building, as the arris of a stone, of a piece of wood, or of any other material. Although the edge of a body may in general language mean the same thing as its arris, yet, in building, the term edge is restricted to those two surfaces of a rectangular solid, on which the length and thickness may be measured, as in boards, planks, doors, shutters, and other framed joinery.

ARROW-ROOT. A very pure form of STARCH, used as food. It is obtained from the tuberous roots of several species of *Marantæ*, a family of herbaceous tropical plants, of which *Maranta arundinacea* is the most esteemed, and produces the best West Indian arrow-root. This starch is more nourishing than that from wheat or potatoes, and is obtained in the following manner:—The fleshy rhizomes, or roots of the plant, are dug up when a year old, and well washed in pure water; they are then either grated or pounded in wooden mortars, and the pulpy matter to which they are reduced is then thrown into a large quantity of water, and agitated. The fibrous parts are collected in the hand, squeezed, and removed, and the remaining milky liquor is strained through a hair-sieve, and left to settle. The white pasty mass, which sinks to the bottom of the vessel, is the arrow-root, which is sometimes subjected to a further washing, and again left to subside, before it is pronounced fit for the market. It is then dried and packed for exportation. The arrow-root of Bermuda is considered the finest.

Several substitutes for arrow-root have been employed, such as *Canna starch*, or *Tous les mois*, obtained from the roots of *Canna coccinea*, extensively grown at St. Kitt's; *Otaheite arrow-root*, which is the starch of *Tacca pinnatifida*; *Portland arrow-root*, from the fleshy roots of *Arum maculatum*, which are acrid when raw, but when roasted or boiled become wholesome, and yield a starch resembling arrow-root, common in the Isle of Portland; and *East Indian arrow-root*, which is obtained from some species of *Curcuma*.

Arrow-root is prepared for use by first mixing it with a small quantity of cold water to the smooth consistency of cream; then adding boiling water, or boiling milk under constant stirring, until it becomes a uniform pasty mixture, which may be flavoured with sugar, nutmeg, and wine. A table-spoonful of arrow-root is sufficient to make a pint of this food.

ARSENIC, (ἀρσενικὸν, masculine, so called from its *masculine* force in destroying man,) resembles the metals in its physical properties, but not so in its chemical, for, instead of forming oxides with oxygen, it forms acids, in which respect it resembles phosphorus. The term *arsenic*, or *white arsenic*, is one of the oxides of the metal *arsenicum*. It is both an oxide and an acid, viz., *arsenious acid*. Combining with bases it forms *arseniates*, many of which are native. Arsenic also occurs as a sulphuret, and is frequently found in combination with other sulphurets, as with the sulphuret of iron, forming arsenical pyrites. During the roasting of the arsenical sulphurets of copper, iron, cobalt, and nickel, abundance of white arsenic is formed, from whence the commercial demand is supplied. Traces of arsenic are to be found in many minerals and in their products, as in sulphuric and sulphurous acids, in zinc, sulphuret of antimony, &c.

Metallic arsenic may be obtained by gradually heating to redness white arsenic, with its weight of black flux,[1] in a small retort contained in a sand-bath: the metal sublimes into the neck of the retort. It is of a steel grey colour, of crystalline texture, very brittle, and of the specific gravity of about 5.8 Heated to a dull red, it sublimes without fusing, so that it would appear to be incapable of assuming the fluid state. According to Regnault, the reason for this is because the temperature at which it fuses is very near that at which it boils, under atmospheric pressure. Volatile bodies throw off vapours far below their boiling points,—a property applicable to solids as well as to liquids. Arsenic gives off abundant vapours at a temperature a little below its boiling point, and can be completely sublimed without attaining its fusing point. But the distance between the fusing point and the boiling point of a body may be indefinitely increased. The boiling point of any substance is the temperature at which the elastic force of its vapour is in equilibrium with the pressure exerted on it. By increasing this pressure the boiling point is necessarily raised; but the fusing point is

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(1) Black flux is made from a mixture of 1 part nitre and 2 parts cream of tartar, thrown in successive small quantities into a [illegible] earthen crucible, heated enough to cause their combustion. From the quantity of tartar used, the flux contains an excess of [illegible] from the tartar [illegible] to convert metallic oxides [illegible] by abstracting [illegible] oxygen.

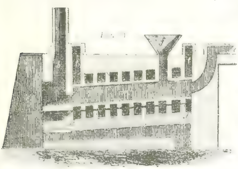
not sensibly affected. We may thus suppose that arsenic is capable of being fused, if, instead of heating it in an open tube, it is heated in a stout glass tube, hermetically sealed: the increased pressure within the tube ought to prevent the ebullition of the metal, and thus cause it to melt long before it boils.[1] Professor Brande states that the experiment has been tried, and that the tension of the vapour burst the tube before the arsenic showed signs of fusion.

Vapour of arsenic is colourless; it has an odour of garlic, which is characteristic; the density of the vapour is about 10.69. The atomic weight of arsenic is 75, and its chemical symbol As.

Arsenic combines with the oxygen of the air at ordinary temperatures; its surface tarnishes, and it becomes covered with a blackish dust; but its metallic lustre is restored by leaving it for some hours in a solution of chlorine.

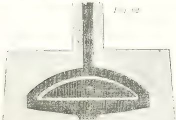
Arsenic is combustible: it burns with a livid flame, with the production of white arsenic. This substance is prepared on a large scale by decomposing, by means of heat, arsenical pyrites. In Silesia there are two mines of this ore, which supply the works at Reichenstein and Altenberg, where large quantities of metallic arsenic, arsenious acid, realgar, and orpiment, are manufactured. The ore is roasted in a muffle furnace, the sole of which *m* is somewhat inclined, as in Fig. 61.

Fig. 61.



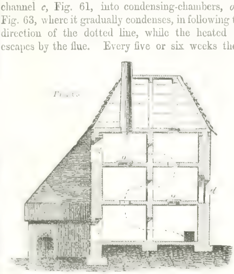
This muffle is 10 feet long and 6 feet wide, and it has a fire, *a a*, under its whole length, the smoke of which escapes by the channels *t t* into the chimney *h*. The muffle is mounted upon brick-work, furnished with numerous openings for the flame. Fig. 62, is a transverse section of the furnace, showing the form of the muffle *m*; *f* is the fire, and *a*, the ash pit.

Fig. 62.



The ore is poured into the muffle by a funnel at *f*, Fig. 61, and is then spread uniformly over the sole by means of a rake. In the course of 12 hours the ore is decomposed, with the production of sulphate of iron and arsenious acid. The latter, in the form of a vapour or of a light powder, is conducted by the channel *c*, Fig. 61, into condensing-chambers, *o o*, Fig. 63, where it gradually condenses, in following the direction of the dotted line, while the heated air escapes by the flue. Every five or six weeks these chambers are cleared out, for which purpose, doors are opened at *d*, and the different chambers can be made to communicate by uncovering the openings at *o*. The purest acid is found in the lower chambers; that in the upper ones contains sulphur. The removal of the acid from these chambers is a dangerous occupation. The workmen wear a leathern dress, carefully fastened round every part of the body, and also over the head, which is further protected by a leathern helmet, furnished with glass eyelits. Under the helmet the mouth and nostrils are covered with a wet sponge or moist linen, for the purpose of filtering the air necessary for respiration.[2]

Fig. 63.



The crude arsenious acid obtained by the above process is refined by a second sublimation, in iron pots covered with drums of sheet-iron, terminating in condensing chambers. A number of these pots are placed in a furnace, and raised to a full red heat, when the acid sublimes into the drums, and forms an internal crust 2 inches thick, the exterior of which is still impure and of a brown colour, and requires to be refined a third and even a fourth time. Flowers of arsenic are condensed in the chambers.

In the treatment of certain metallic arsenio-sulphurets, the principal object is to obtain the metal which is combined with the arsenic; in this case the ore is roasted on the hearth of a reverberatory furnace, and the sulphur, which is converted into sulphurous acid, is allowed to escape up the chimney; but the

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(1) Regnault, Cours de Chimie.

(2) Dumas, Tome Quatrième. The same excellent authority states that the health of the workmen engaged in the arsenic works requires particular care. Two small glasses of olive oil are administered to each man daily. His food consists chiefly of leguminous vegetables eaten with plenty of butter, with very little meat, but that which is eaten is very fat. Alcoholic drinks are positively to be avoided.

arsenic, which is converted into arsenious acid, is condensed in conduits placed between the furnace and the chimney.

Arsenious acid (AsO_3) when newly prepared, consists of vitreous masses perfectly colourless; but when the fragments are left some time, they become opaque, and assume the appearance of porcelain. This change proceeds gradually from the surface to the centre; for when broken, the external crust is like porcelain, while the interior is vitreous. This vitreous portion is three times more soluble in water than the opaque portion, and dissolves more rapidly. According to M. Guibourt, 100 parts of water contain in a saturated solution—

At 60° 1.25 parts of opaque acid, and 0.96 of transparent acid.
At 212° 11.47 ,, ,, 9.68 ,,

Which being left to cool during two days, is found to contain—
2.90 ,, ,, 1.78 ,,

Under the influence of cold water, the vitreous acid becomes opaque: mechanical division has the same effect, for the vitreous acid reduced to fine powder is not more soluble than the opaque.

Arsenious acid reddens litmus in the same manner as feeble acids. It has no smell at ordinary temperatures, but a pinch of it dropped upon a live charcoal exhales the characteristic smell of garlic, which arises from the metal itself, a portion of the acid being decomposed by this process. The specific gravity of arsenious acid is 3.6. It combines with bases and forms *arsenites*. The arsenious acid of commerce is used in large quantities in the preparation of green colours. Arsenite of copper is of a beautiful green colour, and forms what is called *Scheele's green:* arsenious acid is also used in medicine, in the manufacture of shot, for dissolving indigo, and in small quantities in the manufacture of flint glass, in order to get rid of the peroxide of iron in the sand, but an excess makes the glass milky. It is the common instrument of destruction in the hands of the poisoner: it is virulently poisonous when taken into the stomach, and also fatal when applied to a wound. Various antidotes have been proposed, but none seem to be effectual. When the poison has been only recently taken, the best plan is to administer an emetic, and then to give a saturated solution in acetic acid of the newly precipitated hydrated peroxide of iron, or a quantity of caustic magnesia mixed with water. These oxides, combining with the arsenious acid, form insoluble arsenites, and thus destroy the effect of the poison. Various delicate tests have been devised for detecting the presence of arsenic in food, and in the human subject after death, but these had always better be left in the hands of the scientific chemist. The poisonous properties of arsenious acid have also been taken advantage of for the destruction of vermin. To destroy mice and rats the poison should be mixed with flour or with lard, but not in too large a quantity, or these animals will not touch it. In another form the poison may be employed with advantage, in the preservation of stuffed birds and other objects in Natural History. Dumas gives the following recipe:—

White soap	100	parts
Arsenious acid	100	,,
Carbonate of potassa . .	36	,,
Camphor	15	,,
Quick lime	12	,,

The soap is to be scraped and melted in a pipkin with a little water at a gentle heat; then add the potassa and the lime, and mix them well together: the arsenious acid is afterwards added gradually and well incorporated. The camphor is reduced to powder by rubbing it up in a mortar, with the addition of a few drops of spirit of wine, and when the soap is cold, this is well mixed in. A portion of this soap mixed with water is applied to the preparation by means of a camel's hair pencil. It constantly exhales the odour of arseniuretted hydrogen, and effectually destroys insects and their eggs.

Arsenic acid (AsO_5) is obtained by distilling nitric acid off powdered metallic arsenic. The union of this acid with metallic oxides produces ***arseniates*** The arseniate of potash is used in calico printing.

Arsenic combines with hydrogen, producing the volatile and highly poisonous gas, arseniuretted hydrogen. It combines also with chlorine, forming *butter of arsenic*. There are various combinations of arsenic and sulphur: one such compound, *Realgar,* occurs native, and is used in the preparation of *white Indian fire*, which consists of 24 parts saltpetre, 7 of sulphur, and 2 of realgar, finely powdered and well mixed. This composition burns with a white flame of great brilliancy. Realgar is of a beautiful orange red colour, and is used in painting. It consists of AsS_2. AsS_3, forms the yellow sulphuret or *Orpiment,* which is the basis of the pigment named *King's yellow*. Native orpiment, the *auripigmentum* of the ancients, is of a brilliant lemon or gold colour.

Arsenic unites with most of the metals, forming alloys which are generally brittle and comparatively fusible. The alloy of arsenic and iron is more brittle, harder and more fusible than iron. Iron with only 2 or 3 per cent of arsenic is very brittle when heated. Arsenic and copper form the alloy called *white tombac*.

ARTESIAN WELLS derive their name from the French province of Artois, the ancient *Artesium,* where extensive researches had for a long period been carried on for the discovery of subterranean water. In these wells the water is obtained by boring instead of digging; a method which seems to have been practised from a very early period in Italy, especially in the environs of Modena, and it does not appear to have been introduced into France until the reign of Louis XIV. It is probable that these wells were known to the ancients, for Niebuhr quotes the following passage from Olympiodorus:—"Wells are sunk in the oases from 100 and 150 to 200 feet in depth, whence water rises and flows over." Shaw also mentions a group of villages in the depth of the Sahara, which have neither springs nor fountains, but the inhabitants sink wells to the depth of 100 or 200 fathoms.

The formation of artesian wells in our own day depends on a practical application of the science of Geology to the Useful Arts, and in order to gain a clear idea of the formation and mode of action of these wells, it is necessary to inquire into the origin of natural springs and fountains, and the conditions under which an ordinary well yields a supply of water.

By the process of evaporation which is carried on at all temperatures, water from the surface of the ocean, from lakes, rivers, and even from the ground, is raised up into the atmosphere and formed into clouds. These clouds are borne from the sea to the land, where they pour down their waters in greater or less abundance. In England the mean quantity of rain is about 31 inches; that is, nearly 3,000 tons of water are deposited in the course of the year upon every acre. A portion of this water, either derived directly from rain, or the sudden melting of snow, forms the flood waters of our rivers; a second portion evaporates from the surface of the soil, and is again taken up into the atmosphere; a third portion supplies drink and fluid nutriment to animals and plants; while a fourth portion finds its way through the pores or fissures of the soil until it reaches some bed of rock through which it cannot pass; and it is this portion which maintains the perennial supplies of wells, springs, and rivers.

It is well known that in sandy districts the rain-water penetrates as through a sieve, and even in mines which have been sunk through limestone rocks, the miners say that the water increases even in the deepest galleries within a few hours after rain has fallen above ground. Springs which issue at various elevations from the chalk cliffs of our coast, are known to be much increased in volume immediately after rain; and it is equally a matter of common observation, that in times of severe drought springs become less abundant, and many dry up altogether. Hence it will be found that springs, wells, and fountains derive all their supplies from the waters of the atmosphere, and only withhold or vary their supplies in accordance with the variation of rain, dew, snow, and evaporation.[1]

In the primary formations, such as granite, porphyry, lava, and other rocks of igneous origin, the rain waters have very limited subterranean passages, and hence each little streamlet must accomplish its course, as it were, by itself, without receiving additions from neighbouring streamlets; and accordingly, in formations of this kind the springs are very numerous and very small, and they appear very near the places where the infiltration of the rain has been effected. It is very different in the secondary formations. These have the appearance of immense basins, (Fig. 68, p. 77,) which seem originally to have been vast hori-

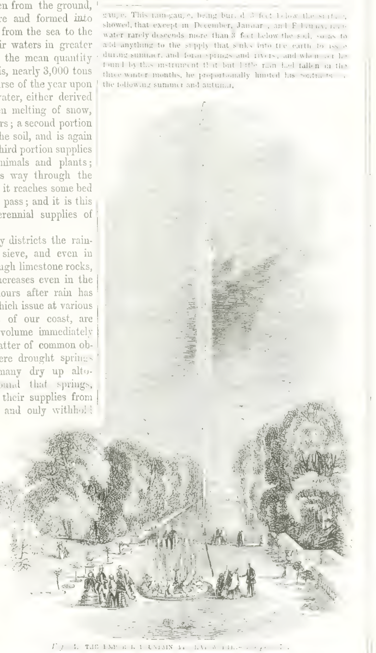

Fig. [illegible]. THE EMPEROR FOUNTAIN AT CHATSWORTH.—[illegible] zontal plains subsequently elevated, and circumscribed by the upheaving force of the primary rocks which now form their hill or mountain boundaries. These basins are arranged in layers or *strata*, some of which are of great thickness, and consist of loose and very permeable sand, and which in rising from the extremity of the basins project or *crop out* on the sides of hills and mountains; the rain-water filtering through these out-cropping strata, may form within them extended sheets of water; but when they are inclined, or *dip* at a high angle, this water rushes towards lower levels, carrying with it by degrees portions of sand, and even of the surrounding rocks, thus forming subterranean rivers which displace portions of the original massive strata, and excavating large caverns where previously there were none.

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[1] Mr. Dickinson, the great paper-maker, who supplies the paper for stamped letter covers, and whose mills are on one of the tributaries of the Colne, has found during many years that the quantity of water in that river during summer varies with the quantity of rain in the preceding winter. He could always tell in the end of February and March how much water there would be in these rivers in the following eight or nine months, and he regulated the contracts he made in every spring, for paper to be delivered in the summer and autumn, by the quantity of water in his winter rain-gauge. This rain-gauge, being buried 3 feet below the surface, showed, that except in December, January, and February, the water rarely descends more than 3 feet below the soil, so as to add anything to the supply that sinks into the earth to issue during summer, and form springs and rivers, and when he found by this instrument that but little rain had fallen in the three winter months, he proportionally limited his contracts for the following summer and autumn.

The tertiary formations are also stratified, or composed of a greater or less number of overlying beds, which, like the courses of a wall, are separated from one another by distinct and well-marked joinings. This formation, like the preceding, is usually basin-shaped, but commonly of far less extent. This shape appears to be due to some alteration in the position of the strata, during which the constituent elements of the tertiary series formed the ridges of the slopes and hills which surround them.[1] During this change in the various strata, they were all more or less violently torn, broken, and detached, so that some are exposed and crop out on the sides and summits of hills.

About two-thirds of the habitable portion of the earth consist of stratified rocks, and geological inquiries obtain much of their precision from the circumstance that the various series of strata are always arranged in a given order. In the tertiary series beds of porous sand occur at various elevations, and the surface-water first penetrates those in which the inclination is great; it then, by its lateral pressure, finds its way into the horizontal branches; so that wherever a succession of sand beds occurs resting on and alternating with impervious strata, we may also expect to find as many subterranean sheets of water.

There are many geological differences between the secondary and tertiary strata, but it will suffice for our present purpose to state, that in secondary formations all the phenomena are exhibited on a much grander scale on account of the prodigious thickness of the strata, of their less frequent alternations, and the greater velocity of the subterranean currents. Hence in the secondary formations natural springs are rare, but when they do occur they are very abundant, and form great chasms and caverns, as in the celebrated rock of Torghat in Norway, which is pierced from end to end by a rectangular opening 150 feet high, and upwards of 3,000 feet long. So, also, the cavern of Guacharo, in the valley of Caripe, in South America, has for its vestibule a vault 72 feet high by 80 feet wide, near the summit of a vast rock of secondary limestone, known as *Jura limestone.* For a length of 1,455 feet it has all the characteristics of the vestibule. The superstitious Indians would not allow Humboldt to advance further than 2,400 feet from the entrance, but he found along this extent a river 30 feet broad rolling along the floor of this magnificent cavern. In the cavern of Adelsburg in Carniola, the river Poick engulfs itself. It appears and disappears many times, and has been traced underground through an extent of 6 miles, as far as a large lake. The Fountain of Vaucluse also issues from subterranean rocks, and pours forth a volume of 13,000 cubic feet per minute, even under ordinary circumstances, and this is sometimes increased to 40,000 cubic feet. But one of the most striking examples of these subterranean sheets of water of a varying level is that of the Lake Zirknitz in Carniola. This lake is about 6 miles long, by 3 broad. Towards the middle of summer, if the season be dry, its surface falls rapidly, and in a few weeks it is completely dry. The openings by which the waters retire beneath the soil may then be seen, in some places quite vertical, in others sloping towards the caverns of the surrounding mountains. Immediately after the retreat of the waters, all the extent of the surface which they covered is put under cultivation, and at the end of a couple of months the peasants are mowing hay, or reaping millet and rye, in the very spot where, some time before, they were fishing for tench and pike. Towards the end of autumn, and after the rains of that season, the waters return by the same natural channels which had opened a passage for them at the time of their departure. This is the regular and usual course; but sometimes a very heavy fall of rain on the mountains which surround Zirknitz occasions the return of the waters to the surface at an earlier period than was expected.

But it is not in hilly and mountainous districts alone that these abundant supplies of subterranean waters are to be observed; for even in flat countries there are caverns in which whole rivers are engulfed. Thus the Guadiana loses itself in a flat country, in the midst of an immense meadow. This explains the fact that, when speaking with admiration of some superb bridge in England or France, the Spaniards remark that they have one in Estremadura upon which 100,000 head of cattle can feed at the same moment. Thus the Drôme in Normandy is lost in the midst of a meadow, in a pit about 30 feet in diameter, known as the Fosse de Soucy. In the same district of France other rivers are lost by degrees. There are from one point to another in the beds of these rivers great gaps, called *bétoirs*, each of which absorbs a portion of the stream. On its arrival at the last bétoir the stream is usually reduced to the size of a trifling rivulet.

There is often in these stratified formations distinct

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(1) These strata were originally deposited horizontally, but sometimes two and three deposits are found in pre-existing basins bounded by older formations. These more recent beds extend horizontally until they come in contact with the older rocks, which enclose them as in a circus. The upper bed only is visible, and it alone receives directly the rain. The surface-water cannot reach the older strata except across the beds which cover it, conditions not very favourable to the formation of subterranean lakes compared with those which exist in basins the boundary sides of which is composed of strata which have undergone the alterations noticed above.

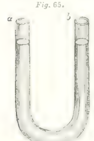
sheets of water at different depths. For example, in the works which have been undertaken in search of coal near St. Nicholas d'Aliermont, near Dieppe, seven great sheets of water were passed through; the first of which was at the depth of 76 feet; the second at 307 feet; the third at 537 feet; the fourth at 645 feet; the fifth at 768 feet; the sixth at 880 feet; and the seventh at the depth of 1,030 feet. Wells which have been sunk in the neighbourhood of London and elsewhere have illustrated the same fact.

But, in addition to these stationary sheets of water in the heart of stratified rocks, water-courses have been found, true subterranean rivers, flowing rapidly in the empty spaces which exist among the impermeable rocks. For example, in boring near the barrier of Fontainebleau, at Paris, the progress had for some time been slow and tedious, as is usually the case in such works; but suddenly the boring tool escaped from the hands of the workman, who saw it fall rapidly upwards of 20 feet, and the transverse handle at the top of the first joint of the borer prevented it from falling any further. When the men endeavoured to raise the instrument, it appeared as if a strong current was carrying it on one side, and causing it to oscillate; but the rapid ascent of the waters of this deep stream prevented further observation. At Port St. Ouen five distinct sheets of water were observed. On penetrating the third sheet, the borer sank suddenly more than a foot; and the current must have been strong, since it impressed the whole of the instrument with a very sensible oscillatory movement. When the end of the borer, filled with debris of the rocks, came, in drawing it up, to the spot where this third sheet of water was, it was not necessary to raise it further, for the current washed away the whole of the debris, an effect which could not have been produced had the water been stagnant.

It will be seen then, that on making an opening from the surface down to these subterranean waters, the water in many cases gushes up to the surface, and forms a perpetual fountain. Now, the question is, What is the power which causes these subterranean waters to rise to the surface and form a constant jet d'eau?

If water be poured into a tube of the shape of the letter U, Fig. 65, it assumes a level, and maintains itself in the two branches *a*, *b*, at heights which are exactly equal. Suppose the left branch of this tube to open towards the top into a large reservoir, which can maintain itself always full; and that the right branch is cut across towards its lower part, so that only a portion of its vertical part remains, and that this portion is fitted with a stop-cock; when the stop-cock is opened, the water will be projected into the air to the same height to which it would have risen had this branch remained entire. In other words, it will ascend as far as it has descended from the level of the reservoir which constantly supplies the opposite branch. In practice, the height of the jet will be somewhat less than the level of the reservoir, on account of friction, the resistance of the air, and opposing currents of ascending and descending particles; but the slight deduction which must on these accounts be made interferes in no way with the principle of fluid level which we are now considering.

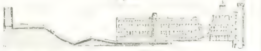
Fig. 65.



This simple experiment is realized on a grand scale in the conduit-pipes which serve to distribute the water of elevated springs or reservoirs to the different parts of a town, or in the subterranean pipes destined to produce jets d'eau in gardens and public squares. When the Romans wished to conduct water from one hill to another, they constructed in the intermediate valleys immense aqueduct bridges, such as the Pont du Gard; and they did so, as we believe, not in ignorance of the hydrostatic principle of fluid levels, but in order to obtain a far more abundant supply than could be furnished by a pipe or series of pipes. The Turks were among the first to adopt the more economical plan, of carrying metal pipes, or a brick or stone tunnel, along the intermediate valley, making it follow the different inflections it might encounter, and finally causing it to ascend the slope of the second hill. The water flowing down this pipe rises, after crossing the valley, to nearly the same height as it had descended.

Now suppose the tube to be carried only to the middle of the valley, and that a single opening on its upper side is made for its escape, the water will in such case be projected perpendicularly upwards, and this jet will rise higher in proportion as the descending current has a great fall. This is the construction of all jets d'eau. The form of the pipe in which the water is conducted is quite a matter of indifference. It may be circular or elliptical, square or polygonal, straight, and of great length, or having many windings and ramifications; and yet the water will equally rise to the height nearly of the level of the reservoir, whenever it has free course to obey the pressure to which it is subjected. Fig. 66 is a section of the reservoir or head of water at New York used for distributing the water of the Croton Aqueduct over the city. (AQUEDUCT.) It will be seen that this reservoir is situated above the level of the houses, and the pipe commencing at its base, being conducted into one of the public squares of the city, forms a beautiful jet d'eau, which rises nearly to the level of the water in the reservoir.

Fig. 66.



Some of the most remarkable ornamental jets d'eau are constructed on this principle. That at Versailles rises to the height of 90 feet; the old fountain at Chatsworth rose to the height of 94 feet; that of Peterhoff, in Russia, 120 feet; that at St. Cloud 160 feet; that at Wilhelmshöhe, in Hesse Cassel, 190 feet, but this fountain is now out of order. The most remarkable fountain in the world is probably the Emperor Fountain at Chatsworth, so named by the Duke of Devonshire in honour of the visit of the Emperor of Russia to this country, a few years ago. This fountain plays to the height of 267 feet; and it is expected, when the reservoir is quite full, to raise it to the height of 280 feet. Fig. 64 (p. 73) represents this fountain in action. For the purpose of supplying it, a new reservoir was constructed, and a conduit or drain cut to convey water into it. This drain commences at Humberley Brook, near one of the bridges on the Chesterfield road, and is increased by tributary springs from the moors, passing along with a gentle fall to the reservoir, for two miles and a half, and winding round a hill in serpentine forms to the proper level. The reservoir covers eight acres of ground; its average depth is about 7 feet; its greatest depth at the head is 13 feet, where there is a solid mass of masonry with a deep valve, to let the water off and on. There is also a waste-pipe for the surplus water. The first length of piping from the reservoir towards the fountain is on the top of the hill, where the ground is comparatively level: this length is 270 feet; the pipe is of 15-inch bore, and the metal three-quarters of an inch thick. The middle length is 1,386 feet; 15-inch bore, and 1 inch metal. The lower length is 959 feet; 15-inch bore, and $1\frac{1}{4}$ inch metal: making altogether 2,621 feet, or 873 yards, 2 feet. At the distance of 181 feet from the fountain is a double-acting valve, which takes about five minutes to open or shut fairly, so that the whole may never be let on or off with a shock to the pipes. For a short distance from the fountain the pipe is $1\frac{1}{2}$ inch thick in the metal, and is secured by a saddle-plate and bracket cast solid to the pipe, and is firmly bolted to a mass of masonry. The end of this large pipe turns up with an elbow, and terminates with a flange, to which the conical tapering part of the jet is fixed. This conical part is about 7 feet high, and terminates in a brass nozzle. Different funnels and nozzles are used, to give variety to the form of the water jet. There are 298 joints in the piping, turned and bored with dip sockets round each, and the weight of the metal in the pipes is about 217 tons. The whole fall of pipe from the reservoir to the fountain is 381 feet, but not of uniform declivity; for the first 450 feet the fall is 1 in 40; for the next 200 feet the fall is very steep, it being 1 in 2; for the next 800 feet it is 1 in 5; and for the remainder 1 in 9.

Bearing in mind the simple but important principle upon which artificial fountains depend, the reader will understand the mode of formation in natural fountains. It is only on the slopes of hills or at their summits that the beds of the stratified series of rocks crop out or are exposed on edge; here it is that the rain-water penetrates and fills the elevated mountain cisterns or hilly reservoirs: these water-carrying beds, after having descended along the sides of the hills, which formerly broke them up while they elevated them, extend horizontally or nearly so along the plains, and in the plains they are often imprisoned as it were between two impermeable or water-tight beds of clay or of hard rock; and thus we may readily conceive the occurrence of subterranean waters in the same hydrostatic condition as the pipes of the fountains just noticed, so that by sinking a pit in the valleys through the upper strata down to the more elevated of the two impermeable beds, between which the water is confined, we thus provide as it were the second branch of pipe, in the form of the U already noticed, or the jet of the fountain at Chatsworth, and the water will rise in this pipe or jet to a height corresponding to that which the water maintains on the side of the hill when it begins to descend. Hence, in any horizontal plane, the different subterranean waters at different elevations may have different powers of ascending: in one place the same water may be projected to a great height, and in another rise no higher than the surface of the soil. All the variations which are met with, arise simply from inequalities of level.

But some of these natural fountains, such as those of Lillers in Artois, throw up their waters in the midst of immense plains, where no hill, not even a hillock, is to be seen in any direction. In such a case, the hydrostatic columns are to be sought for some miles off, hundreds if necessary. The existence of a watery subterranean communication 300 miles in extent, is no objection when 300 miles of country have the same geological constitution. Even at the bottom of the ocean, springs of fresh water project vertically to the very surface. This water evidently proceeds from the land by natural channels, which rise higher than the surface of the sea. On one occasion when Buchanan was becalmed in the Indian ocean, he discovered an abundant spring of fresh water, at the distance of 125 miles from Chittagong, and 100 miles from the neighbouring coast of the Sunderbunds.

These remarks will receive further illustration from the following diagram, Fig. 67. Suppose a basin, composed of permeable strata EFG alternating with impermeable strata HIKL, to have the margin of all these strata continuous in all directions at one uniformly horizontal level AB; the water which falls in rain upon the extremities of the strata EFG, would accumulate within them, and fill all their interstices with water, up to the line AB; and if a pipe were passed down through the upper into either of the lower strata, at any point within the circumference of this basin, the water would rise within it to the horizontal line AB, which represents the general level of the margin of the basin. A disposition s

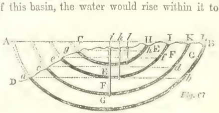


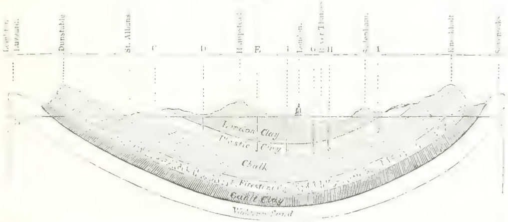
Fig. 67

regular never exists in nature; the extremities or outcrops of each stratum are usually at different levels, *a*, *c*, *e*, *g*. In such cases the line *a b* represents the water-level within the stratum G; below this line, water would be permanently present in G; it could never rise above it, for it would be relieved by springs that would overflow at *a*. The line *c d* represents the level above which the water could never rise in the stratum F; and the line *e f* represents the highest water level within the stratum E, the discharge of all rain waters that percolated the strata EFG, being thus effected by overflowing at *e*, *c*, *a*. If common wells were sunk from the surface *ikl*, into the strata GFE, the water would rise within them only to the horizontal lines *ab*, *cd*, *ef*. The upper porous stratum C, also, would be permanently loaded with water below the horizontal line *g h*, and permanently dry above it.

The following section is intended to explain the rise of water in artesian wells in the London basin, from permeable strata in the plastic clay formation and subjacent chalk. The water in all these strata, as already explained, is derived from the rain which falls on those portions of their surface that are not covered by the London clay, and is upheld by clay beds of the gault beneath the chalk and fire-stone. Thus admitted and sustained, it accumulates in the joints and crevices of these strata, to the line BA, at which it overflows by springs, in valleys, such as that represented at C. Below this line all the permeable strata must be permanently filled with a subterranean sheet of water, except where faults or other disturbing causes afford local sources of relief. Where such do not interfere, the horizontal line BA represents the level to which water would rise by hydrostatic pressure in any perforations through the London clay, either into sandy beds of the plastic clay formation, or into the chalk; such as those represented at DEFGHI. If the perforation be made at G or H, where the surface of the country is below the line BA, the water will rise in a perpetually flowing artesian fountain, as it does in the valley of the Thames between Brentford and London.

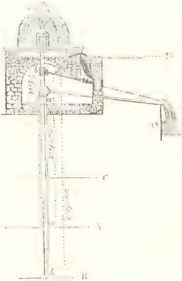
In proportion as the number of Artesian wells is increased, the height to which the water ascends in each becomes diminished, and the general application of them would discharge the subterranean water so much more rapidly than it arises through the interstices of the chalk, that fountains of this kind would soon cease to overflow, although the water within them would rise and maintain its level at the surface of the land. At Brentford there are many wells which continually overflow their orifices, which are only a few feet above the level of the Thames. In the London wells, the water rises to a less level than in those at Brentford, and it is by no means certain that an adequate supply of water for the whole of London could be obtained by boring, as has been proposed. The water which supplies the fountains of Trafalgar Square, rises only to within about 16 feet of the surface, and it is pumped up by a steam engine, into reservoirs at the back of the National Gallery. After supplying the fountains, the water goes to supply some of the public offices in the neighbourhood of the Horse Guards, and the remainder is returned into a reservoir connected with the steam engine, so that it can be pumped up and used a second time if necessary.

Fig. 68.



The mode of action of an Artesian well will be understood from the section, Fig. 69, representing a double fountain at St. Ouen, which brings up water from two water-bearing strata at different levels below the surface of the soil E. In this double fountain the ascending forces of the water in the two strata A and B are different; the water from the lower stratum B, rising to the highest level *b*″; that from the upper stratum A, rising only to *a*′. The water from both strata is thus brought to the surface by one bore hole, of sufficient size to contain a double pipe, viz. a smaller pipe included within the larger one, with an interval between them for the passage of water; thus, the smaller pipe *b*, brings up the water of the lower stratum B, to the highest level of the fountain *b*″; whilst the larger pipe *a*, brings up water from stratum A to the lower level a'. Both these streams are employed to supply the canal-basin D at St. Ouen, above the level of the Seine. Should the lower stratum B contain pure water, and that in the upper strata A C be tainted, the pure water might by this apparatus be brought to the surface through the impure, without contact or contamination.

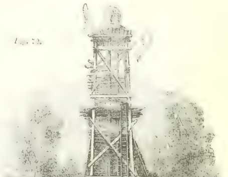
Fig. 69.



But where a single pipe is used, as is generally the case, if the boring penetrates a bed containing impure water, it is continued deeper until it arrives at another stratum containing pure water; the bottom of the pipe being plunged into this pure water, it ascends within it, and is conducted to the surface through whatever impurities may exist in the superior strata. The impure water is excluded by the pipe from mixing with the pure water ascending from below.

One of the most remarkable Artesian wells of our own time is that of Grenelle, in the Paris basin. It was undertaken in 1834, up to which time no successful artesian sinking had reached a greater depth than about 1,000 feet. It was calculated that after passing through the tertiary beds, and the chalk, the upper green-sand would be reached at a depth of 1,200 or 1,500 feet. Operations were commenced with an auger of unusual dimensions, viz. 1 foot in diameter; the borings brought up, in succession, the alluvial soil and subsoil, and the tertiary sands, gravels, clays, lignite, &c., until the chalk was reached. They then bored through the hard upper chalk down to the lower chalk with green grains; the dimensions of the auger being reduced at 500 feet to 9 inches in diameter; at 1,100 feet, to 7½ inches; and at 1,300 feet, to 6 inches in diameter. In the course of these borings, numerous accidents occurred. In May, 1837, at the depth of 418 yards, the hollow tube with nearly 90 yards of the boring rods attached to it broke, and fell to the bottom of the hole, and fifteen months were occupied in extracting the broken fragments, of course delaying the work for that period. In April, 1840, in passing through the chalk, the chisel attached to the boring-rod fell off, and several months were occupied in recovering it. A similar accident occurred a second time, but instead of attempting to recover it, it was driven into the stratum, which happened to be gravel. When the calculated depth of 1,500 feet had been reached without any result, the Government became disheartened, and the public patience exhausted. On the urgent representation of M. Arago, the sinkings were continued, until at length, on the 26th of February, 1841, the rod suddenly descended several yards. They had pierced the vault of the subterranean waters, and in the course of a few hours the water rushed up violently from a depth of 1,800 feet. The first rush brought up an immense volume of water mixed with sand and mud, and at a high temperature. It rose many feet above the surface, and the force was so great that considerable injury was done to the boring rods, and it was some time before the shaft could be sufficiently cleared for the full discharge to issue without interruption. The pipe by which the water reached the surface was carried to a height nearly on a level with the source of the supply. The pipe as it rose from the ground, and the scaffolding which supported it, are shown in Fig. 70, where the water is represented flowing into a circular iron reservoir, from which it was conveyed by another pipe to the ground. Since the tubes have been completed, about half a million of gallons of perfectly limpid water have been supplied by this well in the course of the twenty-four hours, at the constant temperature of 82° Fahr.

Fig. 70.



The temperature of the water of Artesian wells is always higher than that of the surface, according to Arago, in the ratio of 2° for every 60 or 80 feet of descent; but according to the observations of Dr. Paterson on eleven Artesian wells in Scotland, the mean increase is 1° for every 48 feet of descent; and the mean of seventeen wells in other places gave 1° for every 53 feet of descent. In one observation the temperature of the well water was 52°, while that of the surface of a spring close by was at the freezing point.

Artesian wells have been sunk to various depths. The greatest depth is that of Grenelle just noticed. The seventh sheet of water found near St. Nicholas d'Aliermont already alluded to, was at the depth of 1,030 feet, and the water rose from it to the surface. As it was not water but coal that was sought for the works were abandoned, but a copious fountain was unintentionally formed, the waters of which issue from a source more than 1,000 feet deep. In the Duke of Northumberland's grounds, at Syon, is an Artesian boring 535 feet deep. The borings passed first through loose gravel and sand, and strong blue clay, to the depth of 410 feet; then through 10 feet of green sand; next through 30 or 40 feet of loose chalk; and lastly into firm, hard chalk. This well rises 5 feet above the surface.[1]

As to the quantity of water from Artesian wells, the supply appears to be in most cases continuous and abundant. In the monastery of St. André, two miles from Aire, in Artois, a fountain has continued for considerably more than a century to rise to the height of 11 feet above ground, and to supply nearly 2 tons of water per minute. At Bages, near Perpignan, is a well which furnishes 333 gallons per minute. One at Tours jets 6 feet above ground, and yields 237 gallons per minute;[2] and at Merton in Surrey is a well which supplies 200 gallons per minute. At Southampton there is an Artesian well which overflows to the height of 5 feet, and yields 10 gallons per minute. At the depth of 100 feet, it supplies to the pumps 48 gallons per minute. The water is from the sandy stratum in the tertiary formations that overlie the chalk which forms the foundation of the geological basin in which Southampton stands. At Brighton, in 1842, a well bored in the chalk to the depth of only 97 feet, gave by pumping with steam, 700 gallons of water per minute. In some cases, the supply of water has been so abundant as to lead to inconvenience. Thus, a case is mentioned in the *Bibliothèque Universelle de Genève*, of an Artesian boring in a garden to the depth of 360 feet, and 4.5 inches in diameter, in which the first discharge of water was so copious as to overflow the whole yard round the house, and to submerge the adjacent cellars. The damage was so great that the neighbours lodged a complaint, and the police interfered. Two or three men attempted to close the bore with a wooden and afterwards with an iron plug, but they were driven back by the violence of the water. A mason then planted several tubes of small diameter over the bore, and thus succeeded in mastering the water.

Artesian wells have not only been employed for providing houses with water, but their waters have also been used as a moving power. In the village of Gonéhem near Bethune, there are 4 borings to the depth of 120 feet: the waters are conveyed into the watercourse of a flour mill, and are also made to subserve other agricultural purposes. The little town of Roubaix near Arras, was in danger of losing its principal means of support, viz. its silk spinning and dye works, from want of water. Artesian wells were sunk, one of which yields 288 cubic yards of water per day, or double the power of a steam engine of 20 horse power. At Tours, an Artesian well pours 237 gallons of water per minute into the trough of a water-wheel 21 feet in diameter, which is the moving power of a large silk manufactory. In another case, at Fontès near Aire, the united waters of 10 wells are made to turn the mill-stones of a large mill, to blow the bellows and to beat the hammers of a nail manufactory.

The constant high temperature of these waters renders them especially valuable during winter, either as a moving power or as a means of thawing and washing away the ice which impedes the motion of water-wheels in time of frost. In Wurtemburg, the water of several Artesian wells is transmitted through metal pipes arranged in large manufactories, and thus a constant temperature of 17° is maintained at a season when the external temperature is at zero. Green houses have been heated in a similar manner, and the Artesian waters of Grenelle have been applied as a source of warmth to hospitals and other public buildings. By introducing the water of Artesian wells into fish-ponds, the extreme variations of the seasons have been prevented. Artificial cress plots have also been formed and supplied by means of these wells with pure water of a steady temperature. The artificial cress plots of Erfurt produce a large annual revenue. Paper mills have also been supplied with the pure water of these wells at periods when heavy rains have made the river water muddy. In the Department du Nord the fine line used in the manufacture of cambric, lawn, lace, &c., is prepared from flax retted in pools which are supplied by Artesian waters: by their purity and invariable temperature, the soluble portions of the flax are more quickly removed and the valuable qualities of the filaments retained in high perfection.

Such are a few of the advantages and practical applications of Artesian wells. They are most available and of the greatest use for domestic purposes in low and level districts, where water cannot be obtained from superficial springs, or by wells of ordinary depth. Artesian borings called *Blow-wells* have long been known on the east coast of Lincolnshire, in the low chalk district between the wolds of chalk, near

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[1] One of the first Artesian wells near London was bored in 1794, at Norland House, on the north-west of Holland House. The water was obtained from the sandy strata of the plastic clay formation, but so much obstruction accompanied the admission of water to the pipes from this formation, that it was found more convenient to pass lower down through these sandy strata, and obtain the water from the subjacent chalk.

(2) The water from these wells rushes up with so much force, that a cannon ball placed in the pipe is violently ejected by the ascending stream.

Louth and the Wash. These districts were without springs until it was discovered that by boring through the clay to the subjacent chalk, a fountain might be obtained which would flow incessantly to the height of several feet above the surface. It has even been supposed that by means of Artesian borings, water may be raised to the surface in the sandy deserts of Africa and Asia; and it is in contemplation to construct a series of these wells along the main road which crosses the Isthmus of Suez.

But if Artesian borings have been in the majority of cases successful, it must not be forgotten that failures do sometimes occur. Thus at Blingel in the valley of Ternoise, three borings were made in 1820; the first became a very beautiful projecting fountain; the other two, very near to the first, gave no water. At Béthune, a boring after having pierced 70 feet of alluvial soil and 30 feet of limestone, brought to the surface a beautiful limpid jet of water. In the garden of the contiguous property, a similar operation of boring produced no water even though the chalk had been penetrated more than 100 feet.

Such cases as these are by no means rare; and M. Arago explains these failures in the following manner: —It must be remembered that these subterranean waters do not form sheets of great extent, and even do not form sheets at all, except at the surface of separation of two distinct mineral beds. On the contrary, in the thickness of those of the beds which are least compact, as in the case of chalk, the water neither exists in any certain defined limits, nor circulates except in trenches between which are found masses of chalk without fissures and hence impermeable. If the bore enters one of these trenches, water will gush up more or less according to the pressure it there sustains; but should the boring be carried on in a very compact portion of chalk, the labour will be lost. If however the bore be carried to the impermeable bed upon which this mass rests, then there would be found not only streamlets and liquid trenches but a plentiful reservoir, and the success of the operation would be complete.

Artesian wells are sometimes curiously affected by the tides. In the Artesian well of the palace of the Bishop of London at Fulham, which is bored to the depth of about 300 feet, the quantity of water is 80 or 60 gallons per minute, according as the tide is high or low. M. Arago explains the effect in cases of this kind, by supposing the subterranean river which feeds the well, also partially to discharge itself into the sea or into a tidal river by an opening of considerable dimensions compared with its own size. If this opening be diminished the pressure will immediately increase at all points of the natural or artificial channels occupied by the subterranean waters, and the flow by the well will become more rapid, or what is the same thing, the level of the water will rise. The flow of the rising tide immediately above the opening by which the subterranean waters discharge themselves, will increase the pressure upon the opening, the effect of which will be similar to that of diminishing its size, so that a less quantity of water will escape into the tidal river. When, on the contrary, the tide is ebbing, the pressure will be diminished and an increased quantity of water will flow from the subterranean courses. Hence it will be readily seen that the flowing and ebbing of the tide must produce a corresponding flowing and ebbing of the water of the well.

There is a description of boring or sinking which M. Arago terms *negative Artesian wells* or *drain-wells.* These are pits sunk for the purpose of transmitting into the earth, water retained at the surface by strata of impermeable clay or stone, thereby rendering extensive districts mere morasses unfit for cultivation. Thus the Plain of Paluns near Marseilles was formerly a great morass which it appeared impossible to drain by surface channels. King René sunk numerous drain-wells which proved effectual, and the waters thus carried off are said to have formed the projecting fountains of the port of Mion near Cassis. The river Orbe in the Jura which descends from the lake of the Rousses, conveys into lake Joux much more water than is removed from it by evaporation. This latter lake, which has no river issuing from it, nevertheless maintains a nearly uniform elevation. "It is," says Saussure, "because nature has provided for these waters subterranean issues by which they are engulfed and disappear. As it is of the greatest consequence for the inhabitants of this valley to preserve these natural drains, without which their arable lands and habitations would be immediately overflowed, they preserve them with the greatest possible care; and when they perceive that they do not take off the water with sufficient velocity, they themselves open new ones. For which purpose all that is necessary is to sink a pit 15 or 20 feet deep, and about 10 feet in diameter in the thin and vertical strata, the summits of which appear on the surface. The waters absorbed by these *entonnoirs,* or funnels, as they are called, are observed to rise from the earth and form a large spring, called Orbe, at the distance of two miles below the southern extremity of the lake." In this passage of two miles the absorbed waters descend 680 feet.

In the winter of 1832-3 a manufacturer of potato-starch at Villetaneuse, a small village about three miles from St. Denis, sunk a pit to the depth of the absorbing stratified beds, and thus got rid of no less than 16,000 gallons of impure water per day, the stench of which had given rise to serious complaints which would probably have compelled him to break up his establishment. After six months of daily absorption, nothing but sand was found at the bottom of the pit, so completely had the nuisance been removed by this means. It is to be feared, however, that the water of neighbouring wells might be injured.

The mechanical details connected with the formation of Artesian Wells, will be found under BORING. Numerous sources of information have been referred to in the preparation of this article, but the editor wishes specially to acknowledge M. Arago's notice in the *Annuaire* for the year 1835, and Dr. Buckland's *Bridgewater Treatise.* The method of sinking common wells will be found under the article WELLS.

ASBESTUS. AMIANTHUS. A mineral substance in which long capillary crystals are arranged in a fibrous mass. Several varieties of hornblende are of this kind, the most beautiful being the flax-like variety, called Amianthus, or mountain-flax. The term Asbestus signifies *indestructible*, while Amianthus means *unstained*, in allusion to the fact that this mineral is neither destroyed nor sullied by passing through fire. Veins of Asbestus occur in serpentine in Cornwall, and in micaceous slate at Glenelg in Inverness. In Upper Saxony, Silesia and Switzerland, Asbestus is found in veins of serpentine; in Bohemia, in metalliferous beds, accompanying magnetic iron-stone; in Dauphiny, in gneiss and mica slate.

The long and silky fibres of Amianthus have been woven into a fire-proof cloth, which in the mass is capable of resisting flame, though a single fibre would soon be reduced to a white enamel. The ancients were acquainted with the art of making this indestructible cloth, and used it to wrap the bodies of the illustrious dead on the funeral pile, that their ashes might not mix with the ashes of the wood. In the year 1702, an asbestus shroud, containing ashes and burnt bones, was discovered in the Vatican at Rome. The scarcity and high price of this material caused its use to be confined to the richest families. It is said that Charlemagne had a table-cloth of amianthus, which he would sometimes throw into the fire, after dinner, to the great astonishment of his guests. Pliny says, that napkins made of this substance were better cleansed by throwing them into the fire than by washing. By the help of gloves made of asbestus, or amianthus, red-hot iron may be safely handled, or the hand may be placed in the midst of flames with impunity. Advantage has been taken of this circumstance, not only to perform various clever tricks, but for the more important purpose of saving human life. The art of making fire-proof cloth was revived by the Chevalier Aldini of Milan, and by him applied to protective uses. It was he who arranged and contrived the fire-proof dress, which enabled its wearer to walk amidst the flames unhurt. Clothing several firemen with these dresses, he caused them to go through various experiments to prove the efficacy of the apparatus, and to inspire them with confidence. They carried bars of red-hot iron, walked over iron-gratings through which the flame of fagots ascended, or plunged their heads into a fire of shavings, kept burning in a large raised chafing-dish. The firemen's dress, as invented by Aldini, consisted of cap, gloves, and stockings of asbestus cloth, while the body was covered with strong cloth steeped in a solution of alum. Outside this was a metallic dress of iron-wire gauze, with a casque or cap, and a mask for the face. The asbestus cap, likewise, covered the face down to the neck, having suitable perforations for the eyes, nose and mouth.

The art of weaving amianthine cloth was anciently accomplished by weaving fibres of flax with those of amianthus, and then passing the cloth through a furnace, by which means the flax was destroyed, while the fire-proof material remained; but Aldini contrived to weave a much stronger cloth without the aid of any foreign substance. The fibres are prevented from breaking by the action of steam, the cloth is made loose in fabric, and the threads are about the fiftieth of an inch in diameter.

ASHLAR. A term applied by builders to the common or free-stones of various sizes as they come from the quarry. This term is also applied to the facing of thin squared stones on the brick and rubble walls of buildings. When the work is smoothed or rubbed so as to take out the marks of the tools by which the stones were cut, it is called *plane ashlar;* most of the public buildings of London, in which stone is used, are treated in this way. When the surface is wrought in a regular manner, like parallel flutes placed perpendicularly, it is called *tooled ashlar*, and is chiefly used in the basements of buildings, but when the surfaces of the stones are cut with a broad tool without much regularity, the work is said to be *random tooled;* when wrought with a narrow tool, it is said to be *chiselled* or *boasted;* if the tools be very narrow, the ashlar is said to be *pointed;* when the stones project from the joints, the ashlar is said to be *rusticated;* in this kind the faces may have either a smooth or a broken surface. According to Mr. Nicholson,[1] neither pointed, chiselled, nor random-tooled ashlar are employed in good work; in some parts of the country *herring-bone* ashlar, and *long-bore random-tooled* ashlar are used. The act of bedding the ashlar-facing in mortar, is called *ashlaring*.

ASHLARING, in carpentry, is the fixing of short upright quarterings between the rafters and the floor in garrets, in order to make more convenient rooms by cutting off the acute angles at the bottom. The triangular spaces on the sides are either left unoccupied or formed into cupboards or closets. Most of the garrets in London are built in this way.

ASPHALTUM or native bitumen, pit coal, lignite or brown coal, petroleum or rock oil, naphtha and a few other substances, are now regarded as products of the decomposition of organic, and especially vegetable matter, beneath the surface of the earth, in situations where water is present but atmospheric air is almost entirely excluded. Being deposited at the bottom of seas, lakes or rivers, and subsequently covered up by accumulations of clay and sand, the organic substances undergo a kind of fermentation, by which the above-named bodies are slowly produced. [See COAL.]—The true bitumens, of which there are a large number, seem to have been produced from coal or lignite by the action of subterranean heat. Asphaltum is also called *mineral pitch*, *Jew's pitch*, *compact bitumen* and *maltha*. It is found in considerable quantities on the shores of the Dead Sea, or *Lacus Asphaltites*, where it is called by the Arabs *Hajar Mousa* or *Moses' stone*. There is a thick bed of asphaltum at Arlona in Albania. It also occurs at Coxitambo near Cuenca in South America. It

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(1) "Architectural Dictionary," by Peter Nicholson, Architect. London. 1819.

abounds also in the West India islands of Barbadoes and Trinidad. In the latter island it forms a lake or rather plain, known by the name of the *Tar Lake*, called by the French *Le Brai*, from its resemblance to and answering the purpose of ship pitch. It lies in the leeward side of the island, on a point of land which extends into the sea about two miles. This cape or headland is about 50 feet above the level of the sea. From the sea it appears a mass of black vitrified rocks, but on closer examination is found to consist of bituminous scoriæ, vitrified sand, and earth cemented together. In some parts, beds of cinders only are found. In approaching it there is a strong sulphurous smell, which is prevalent in many parts of the ground 8 or 10 miles from it. The bituminous plain is separated from the sea by a margin of wood that surrounds it. From its colour and even surface, it appears like a lake of water, and in hot and dry weather, its surface to the depth of an inch is liquid, and so cohesive that no one can walk upon it. It is circular in form and about 3 miles in circumference. On first approaching it, it has the appearance of a plane as smooth as glass, but a nearer inspection shows it to be broken up by numerous cracks and fissures, resembling the markings on the back of a turtle, which being sometimes filled with water, make the whole surface appear level. The bitumen resembles pit coal in consistence and appearance, only its colour is rather more grey. It breaks into small fragments of a cellular appearance, and glossy, with a number of minute shining particles interspersed through its substance; it is very friable, and when liquid is of a jet black colour. Some parts of the surface are covered with a thin brittle scoria a little elevated. Mr. Anderson, who describes this lake,[1] could form no idea as to its depth, for in no part could he find a substratum of any other substance, and although the smell of sulphur was strong, no appearance of that substance was to be detected. The general odour, however, was that of pitch. No impression could be made on the surface without an axe; at the depth of a foot it was a little softer, with an oily appearance, in small cells. A small portion held in a flame hisses and cracks like nitre, emitting minute sparks with a vivid flame. A piece put into the fire boils up a long time without suffering much diminution; a thin scoria then forms over the surface, under which the rest remains liquid. The absorption of heat by the black mass of the lake is so great, that the rain-water is evaporated from it very quickly. The bitumen is much used for ships' bottoms, and is said to kill the Borer or Teredo, which is so destructive to ships in that part of the world.

In many parts of the woods this substance is found in a liquid state: it smells stronger of tar than when indurated, and adheres strongly to anything that it touches. This liquid substance is *petroleum* or naphtha, holding asphaltum in solution. It is found in various parts of Europe, but most abundantly in the Birman Empire. "The town of Rainanghong is the centre of a small district, in which there are some hundred petroleum wells in full activity. The district in which they are situated consists of a sandy loam, resting upon alternate strata of sandstone and indurated clay: under these is a layer of pale blue argillaceous schistus, impregnated with petroleum of considerable thickness, and resting upon coal. The petroleum flows into the well when it is sunk a few feet into the schistus, and when it begins to fail, the well is deepened. It is remarkable that no water ever penetrates into these wells. The annual quantity of petroleum produced by the district, exceeds 400,000 hhds. The uses of petroleum where it abounds are very important: it serves the lower classes instead of oil for lamps, and when mixed with earth or ashes it answers the purpose of fuel. A composition of petroleum and resin is an excellent material for covering wood-work, and paying the bottoms of ships and boats, as it protects the timber from the attacks of insects and worms. When rectified by distillation it affords naphtha.[2]

Asphaltum varies considerably in purity, according to the quantity of different earthy substances mingled with it. When nearly pure its colour is almost black or dark brown, and it does not soil the fingers. When rubbed, it gives off a pitchy odour. Its specific gravity varies with its purity, from about 1 to 1.10. It is insoluble in water; but alcohol takes from it about 5 per cent. of a yellow resin, and ether dissolves it to the extent of about 70 per cent. Asphaltum is very inflammable: it burns with a red smoky flame, and consists principally of a substance which M. Boussingault names *asphaltene*, composed of $C20\ H16\ O3$.

A few years ago, as M. Dumas remarks, asphaltum produced an industrial fever, unparalleled in the annals of the useful arts. Its valuable properties were strongly exaggerated, and it was applied to uses for which it was evidently unfitted. Repeated failures led to a reaction, and asphaltum soon fell into a neglect as unmerited as the previous high degree of favour with which it was regarded.

During this period of excitement, several companies were formed in England, for the purpose of making asphaltum roads and pavements, for paving terraces, railway platforms, kitchens and stables, for roofing, and for protecting buildings from damp. In 1837, Mr. Claridge obtained a patent for the peculiar application to these purposes of the asphaltum from Seyssel on the Rhone, in the department de l'Ain, and also published a pamphlet entitled "Instructions for the use of the Seyssel Asphaltic Mastic," from which the following particulars are derived.

The principal ingredient in this mastic is a dark brown bituminous limestone, found near the Jura Mountains. The stone is reduced to powder and mixed with a portion of mineral tar when intended to be applied as a cement, as in covering roofs, lining tanks, &c.; but when intended to be used for flooring and for pavements, sea grit is used in addition. The

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(1) "Philosophical Transactions of the Royal Society," Vol. [illegible]

(2) Cox: "Asiatic Researches." Aikin. "Dictionary of Chemistry."

ingredients are exposed for some hours to a strong heat in large caldrons, and kept constantly stirred by machinery. The mastic thus formed, is run into moulds about 18 inches square by 6 inches deep, and formed into blocks, weighing from 112lbs. to 130lbs. each. In this state it is sold for use, but it requires to be remelted on the spot where it is to be applied, for which purpose, small portable furnaces and caldrons, Fig. 71, are provided. 1lb. of mineral tar is first put into the caldron, and when this is melted, 56lbs. of the mastic are added, the whole being stirred repeatedly with a curved loop of iron attached to a handle, Fig. 72, so as to detach any portions of the mastic from the sides and bottom of the vessel and prevent burning. When the contents are properly melted, the caldron is covered up for a quarter of an hour, after which another 56lbs. of mastic are stirred in. The caldron is again covered for a short time, and additional quantities of tar and mastic are added in the proportion of 1lb. of the former to 1 cwt. of the latter, until the caldron is full. When the whole is completely melted and fit for use, jets of light smoke will proceed from the mixture, and the mastic will drop freely from the stirrer. The only kind of tar to be used in this mixture, is that with which the limestone is impregnated. If the mastic is required to be very stiff, as for paving kitchen floors, a smaller proportion of tar is to be used. In such cases, also, a larger proportion of grit is mixed with the mastic, and when it is desired to convert fine asphalte into coarse, 30lbs. of fine clean grit are to be added to 112lbs. of mastic, with from 1lb. to 2½lbs. of tar.

Fig 71

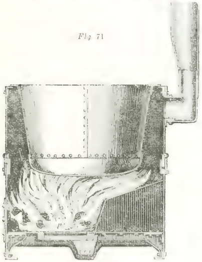


Fig. 72.

When the melting is complete, the mastic is conveyed quickly to the spot where it is intended to be used, either in iron ladles or heated iron buckets. The caldron ought to be as close to the work as possible, and in covering [illegible] it may be hoisted to the top of the building; taking care, however, to protect the finished part from the heat of the furnace by a layer of [illegible].

In forming foot or carriage roads, it is important to secure a good foundation, either by removing or ramming the natural soil and laying [illegible] concrete,

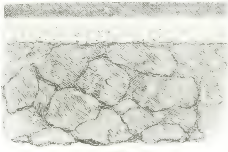
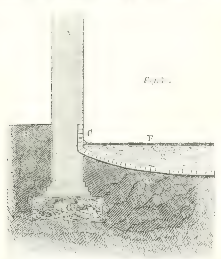


Fig. 73.

c, Fig. 73, formed by mixing 7 parts of clean river sand or gravel, and 1 part fresh grey-stone lime in powder. The quantity of water should be only just sufficient to moisten the mass, which must be immediately levelled and rammed solid. The hollows must then be filled up with a finer concrete, B, and the whole be allowed to dry before laying the asphaltum. Unless this precaution be attended to, the heat will convert the moisture of the concrete into vapour, and fill the asphaltum with air holes. This may to a great extent be prevented by sifting fine cinder dust over the concrete, and in rainy weather if the work cannot be protected by a tarpaulin, sheets of tarred brown paper may be spread over the concrete and the asphaltum be poured over these. The thickness of the layer of asphaltum, A, is regulated by slips of wood, arranged so as to divide the pavement into compartments not exceeding 30 inches wide, when only one workmen or spreader is employed, but double that size when two spreaders are employed. The work is levelled by a curved wooden spatula assisted by a floating rule or long straight ruler, stretching across the layer of asphaltum, over which it is moved backwards and forwards, the wooden gauges supporting its ends. If the surface is intended to be smooth, a mixture of equal parts of silver-sand and slate dust, or of 2 parts silver-sand to 1 of dead plaster of Paris or powdered chalk, is sifted over the asphalte before it is perfectly set, and rubbed in with a flat heavy tool of wood. If the pavement is required to be rough, clean sharp grit is sifted thinly over it and beaten into the mastic with a heavy wooden block. When one portion of the pavement is complete, it is desirable to proceed to lay the next but one, leaving the intermediate space to be filled in afterwards when the first layer is quite cold and firm, so as to prevent its being injured. In laying these pavements the parts most exposed to wear are somewhat increased in thickness. In laying them upon suspension bridges or other flexible surfaces, the concrete is spread on a planked flooring, the joints of which are covered with battens nailed at one edge only to allow the necessary play: a sheet of thin canvass is then spread evenly over the concrete and secured with nails, and upon this the mastic is spread. By mixing differently coloured sands with the mastic, and disposing it in patterns, imitations of mosaic work may be formed.

In the application of asphaltum with a view to exclude damp, as in the floors of cellars and basements, a brick invert laid in asphalte as a cement should be used, as at D, Fig. 74. Asphalted bricks and tiles for such purposes are prepared by heating them, and placing them in rows upon a flat surface between gauges rising to a sufficient height to allow a layer of the mastic a quarter of an inch thick to be spread over them: before the mastic is quite set, the bricks are separated from each other by passing a knife between them. In Fig. 74, the arrangement is shown for excluding water from a cellar. A is a section of the wall, B the watermark on the outside, C an asphalted brick lining, D a similar lining for the invert, E and G a bed of concrete, and F the asphalte floor of the cellar. In some cases, alternate layers of concrete and asphalte may be adopted instead of a brick invert. Directions are also given in the pamphlet for making skirtings of asphaltum, for lining cisterns, and for covering roofs, &c., but enough has been stated to show the general method of applying this material. The thickness of asphaltum used for pavements, varies from half an inch to an inch and a quarter, the former being sufficient for common floors and court-yards, and the latter for carriage pavements. A thickness of from half an inch to five-eighths is sufficient for roofs and the coverings of arches for preventing the passage of water, and for the lining of tanks and ponds; and about a quarter of an inch is sufficient for the ground line of brickwork to prevent damp from rising.



An asphaltum surface admits of easy repair. By placing some hot mastic upon the place requiring it, the part may be cut away without injuring the adjacent work. The mastic thus removed may be remelted, and the edges of the old work being cut square, the hot material will readily adhere to them if free from dust and moisture.

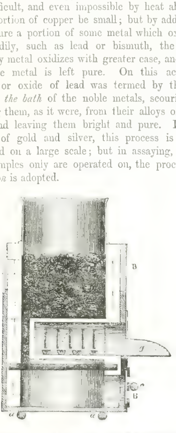
ASSAYING is a branch of chemical analysis, the object of which is, to determine the quantity of gold or silver in any mixture with the baser metals. It thus differs from chemical analysis, which takes account of *all* the ingredients of the body under examination. As gold and silver have for many ages afforded the most obvious standard of value in civilized countries, and considering what vast quantities of coin, plate, trinkets, and plate ornaments are being constantly produced, it was of great importance to persons who deal in such articles, to be able to decide quickly, and with certainty, on the exact portion of alloy which each piece might contain, and its exact weight to the minutest subdivision of weights. At an early period, in this country the trade of the goldsmith not only comprised as now the dealers in or makers of gold and silver articles, but also that trade which has, since the separation of the two ancient branches, received the name of Bankers. No tax was then, as now, levied on manufactured plate, but all articles made of gold and silver were to be of the same degree of purity as the coin of the realm. "Whatever was manufactured in London or in some of the larger places, was ordered to be assayed and stamped by the warders of the craft in such town; but whatever was made in places 'where no touch was ordained,' was to be stamped by the maker, and if found beneath the proper standard, it was confiscated to the crown.[1] In this state of affairs, any article of plate would be of the same value, in equal weights, as gold or silver in ingots; and hence, as occasion might require, the vessels being worth no more than their weight, would be on every pressing emergency readily converted into coin. The workmanship of plate would in that age cost but little, as luxury had not reached the point in that kind of art, which it soon afterwards attained in the hands of Benvenuto Cellini at Florence, and of his successors in the other parts of Europe. The taste displayed in the forms and decorations of gold and silver utensils was very coarse, both in France and in England. Voltaire, in his General History, says, that the work of the goldsmiths in Paris was so bad that the King, (Louis XII.) in 1501, forbade the manufacture, so that the French had their plate from Italy. There seems good reason to believe, that the English of that period did not excel the French artisans in the fabrication of gold and silver articles. We may thus account for what we find often stated in the records of that age, that the religious houses, the nobility, and rich individuals, gave up to the monarch, on pressing emergencies, their plate for the public service. Such a surrender in the present day, when a heavy tax and the workmanship of artists make plate of silver of more than double its value in weight, would be deemed a most oppressive requisition, whereas at the period referred to, the difference between making

(1) Bills of Parliament, 2d Henry VII cap. 12 and 13

payments in coined money or in manufactured gold and silver, would amount but to a trifle." [1]

Although the assay of the precious metals is very simple in principle, great skill is required in assaying. A skilful assayer is able from the sample of a few grains to determine the standard of very large masses of the most valuable metals. The principle of assaying is as follows:—when gold, silver, and platinum are exposed to the air, either in the solid state or in a state of fusion, they do not oxidize like the other metals, but retain their metallic lustre, on which account they obtained their name of *perfect* or *noble* metals. Hence, when a noble metal is alloyed with an inferior metal, if the alloy be melted in contact with the air, the latter will gradually become oxidized, and the scales of oxide rising to the surface can be removed from time to time, until the whole of the baser metal is separated. When the baser metal does not oxidize very readily, as is the case with copper, this separation becomes more difficult, and even impossible by heat alone if the proportion of copper be small; but by adding to the mixture a portion of some metal which oxidizes very readily, such as lead or bismuth, the more refractory metal oxidizes with greater ease, and thus the noble metal is left pure. On this account, litharge or oxide of lead was termed by the old chemists *the bath* of the noble metals, scouring or cleansing them, as it were, from their alloys of base metal, and leaving them bright and pure. In the refining of gold and silver, this process is often conducted on a large scale; but in assaying, where small samples only are operated on, the process of *cupellation* is adopted.

Fig. 75.



Cupellation is carried on in a small furnace capable of being raised to a heat sufficient to melt gold. In Fig. 75, BB, is a section of an assay furnace, which is capable of being moved forwards or backwards on two iron rollers *a a*; *b* is the ash pit with the grate above it, *c* is one of the ash pit dampers for regulating the draught, *g* is a mouth-plate for holding pieces of ignited charcoal. In the middle of this furnace is placed an earthen vessel *f*, called a *muffle*, of an oven form, vaulted at top with a level floor at bottom; it rests upon a plate which is covered with loam nearly an inch thick: it is open at one end and closed everywhere else except a few narrow slits through the top and sides. It is shown separately in Fig. 76, with the *muffle plate* Fig. 77, of the same size as the bottom of the muffle; the open end comes in contact with a door at the side of the furnace, and is generally luted thereto, so as to separate it entirely from the burning fuel. The body of the muffle is surrounded with coals, and before cupellation, is gradually heated to a glowing redness. Its use is to protect the small crucibles or cupels, ranged on its floor, from any impurities from the fuel, and at the same time to afford the melted metal a free access of heated air to promote the oxidation. The *cupels*, shown in section within the muffle, Fig. 75, are cubical or circular in form, with a shallow depression at the top to contain the metal, and small in proportion to the size of the muffle, so that a number of them may be at work at the same time. They are made of such substances as are not acted on by the fused oxides, and their texture is sufficiently loose to allow these oxides to penetrate them readily, and yet admit of being handled. Many substances fulfil these conditions, but the ash of burnt bone is generally used. The ash is powdered and sifted, and then repeatedly washed with water, to remove all saline and soluble matters: when dried, it consists of phosphate of lime with a little carbonate. This substance made into a paste with water or beer, is pressed into a mould to the proper shape: it is then taken out and dried at a gentle heat, and is lastly ignited to expel all moisture.

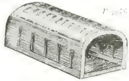


Fig. 76.

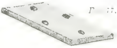


Fig. 77.

Before the cupels are put into the muffle, a little powdered chalk or sand is sprinkled on the floor of the muffle, to prevent the adhesion of the cupels by the litharge soaking through them. As the cupels cannot absorb more than their own weight of litharge, the quantity of fine metal to be assayed should not require more lead than the weight of the cupel.

For the assay of silver a clean piece of the metal is taken, not more than 36 grains, and less if the alloy appear to be considerable. It is flattened and weighed in a very sensible balance. It is then wrapped up in the requisite quantity of pure lead rolled out into a sheet; or the silver and the lead are folded together in a piece of paper. The muffle and the cupel being at a full red heat, the silver and the lead are put into the cupel with a pair of pincers, when they immediately melt. Aikin gives a beautiful and accurate description of the phenomena:—"The melted metal begins to send off dense fumes, and a minute stream of red fused matter is seen perpetually flowing from the top of the globule down its sides to the surface of the cupel, through which it sinks and is lost to view. This fume and the stream of melted matter consist of the lead oxidized by the heat and air, in one case volatilized, in the other vitrified, and in sinking through the cupel it carries down with it the copper or other alloy of the silver. In proportion to the violence of the heat is the density of the fume, the violence with which it is given off, the convexity of the surface of the globule of melted metal, and the rapidity with which the vitrified oxide *circulates*, (as it is termed,) or falls down the sides of the metal. As the cupellation advances, the melted button becomes rounder, its surface becomes streaky with large bright points of the fused oxide, which move with increased rapidity, till at last the globule, being now freed from all the lead and other alloy, suddenly *lightens*;[1] the last portion of litharge on the surface disappears with great rapidity, showing the melted metal bright with iridescent colours, which directly after becomes opaque, and suddenly appears brilliant, clean, and white, as if a curtain had been withdrawn from it. The operation being now finished, and the silver left pure, the cupel is allowed to cool gradually, till the globule of silver is fixed, after which it is taken out of the cupel while still hot, and when cold accurately weighed. The difference between the globule and the silver at first put in, shows the quantity of alloy, the globule being now perfectly pure silver, if the operation has been well performed."[2] Aikin states, that at the Mint two assays are always made of the same mass of metal, and no sensible difference, as ascertained by scales which turn with [illegible]th of a grain troy, between the weight of the two buttons is allowed to pass. If they differ, the assay is repeated. The process is well performed, if the button of silver adheres but slightly to the cupel; if the shape is globular above and below, and not flattened at the margin; if the button be quite clean and brilliant, showing the beautiful white of pure silver, and not in any degree fouled or spotted with any remaining litharge: the surface of the metal must be disposed in scales or laminæ, the effect of sudden crystallization, which gives it a play of light and a striated lustre, very different from that of a perfectly even surface of a white metal, however pure. Examined by a microscope, this striated surface is still more striking; but when any alloy remains in the silver, the surface, although brilliant, appears smooth as if varnished.

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[1] Jacob on the "Precious Metals." London 1831.

In ordinary assays of gold or silver, copper is the alloy usually met with. If the metal be nearly pure, the cupel round the bottom is only stained yellow by the litharge. If copper be present, it leaves a brown grey stain. The other metals except bismuth scarcely penetrate the substance of the cupel, but remain on the edges of its cavity in the form of coloured scoriæ, of which iron is black, tin grey, and zinc a dull yellow.

The time required for one assay, from putting the metal into the hot cupel to the *lightening* or purity of the button, is generally from 15 to 20 minutes, but the time is not of much consequence, as the button is equally pure after a rapid as after a slow cupellation. If the heat be too great, there is danger of error from the volatilization of the silver, but it is desirable to admit as much air into the muffle as possible consistent with a due regard to temperature. It is important also to attend to the gradual cooling of the button, because pure silver in a molten state absorbs oxygen from the air, and in returning to the solid state the whole is again expelled, so that if the cooling be rapid, the silver is spirted out in arborescent shoots, and some minute portions are thus thrown out of the cupel, and the assay is spoilt.

The proportion of lead to the silver to be assayed is also a point of importance. If too little lead be used, the button is very flat, rough at the edges, of a dull colour, with blackish spots, strongly adherent to the cupel, and foul with scoriæ on and about the button. If an excess of lead be employed, a small portion of the silver will be carried down into the cupel, and thus the sample of silver will be reported a little less pure than it really is. The quantity of lead required for each case of cupellation was formerly estimated by the use of *touch-needles*, or small slips or bars of metal made with pure silver, alloyed with known proportions of copper in a regularly increasing series, from the least to the greatest proportion ever required. The silver to be assayed was then compared with the touch-needles, in colour, tenacity, and other physical characters, and its alloy was estimated by that of the needle which it most resembled. These needles are seldom used now, as an experienced assayer is able to judge of the alloy by the ease or difficulty with which it is cut, the colour and grain of a fresh cut surface, the malleability, the change of surface when red-hot, and the general appearance.

The *assay of gold* is somewhat more complicated than that of silver. If silver be mixed with gold, although the latter be in very small proportion, it becomes a *gold assay*. Copper or any other base metal mixed with gold may be separated from it by cupellation, but the affinity of copper for gold is so strong as scarcely to be overcome by this method, unless a certain quantity of silver be added. Consequently, a subsequent operation is required to separate the gold from the silver as mixed in the button after cupellation. Gold is frequently alloyed with silver in some foreign coins, and in some kinds of manufacture. The separation of gold from silver is called *parting*, and is performed with dilute nitric acid, which dissolves the silver and leaves the gold untouched. If, however, the gold be in considerable proportion, it protects the silver from the action of the acid, and the parting is imperfect. In such case it is necessary to add silver, so as to give it a great excess over gold. About 3 parts silver to 1 part gold is the general proportion, and hence the process of parting is also called *quartation*, the relative proportion of gold being reduced to only one quarter of the mass, but any greater proportion of silver may be parted with equal certainty. As the entire quantity of materials for the assay amounts to only a few grains, and as the intimate mixture of the silver is of great importance, it is usual to cupel them together with lead, so that they may be thoroughly combined into one small neat globule. The process is similar to the cupellation of silver, only a greater heat is required, which may be safely employed, as none of the mixture of gold and silver is lost by volatilization as pure silver is. The copper is worked off along with the litharge, but any minute portion of lead is got rid of by a second fusing. The cold button is then flattened with a hammer, again heated red-hot, and slowly cooled to anneal it and increase its malleability. It is then extended into a small plate, by being passed between rollers of polished steel, and is next rolled up in a loose coil called a *cornet*. This is put in a glass mattrass called a *parting glass*, and about twice or thrice its weight of pure dilute nitric acid is poured over it. The whole is slightly warmed, when a portion of the acid begins to decompose, and gives off red fumes of nitrous acid, and in about 15 or 20 minutes the whole of the silver is washed out, leaving the gold still coiled up in a slender brittle mass. The hot acid solution of silver is carefully poured off, and fresh acid, rather stronger, is added and heated for a few minutes, to clear away the remains of the silver. This is decanted off and added to the former solution. The parting glass is then filled with hot distilled water, and as it is of importance, for the sake of accuracy, to get out the cornet without breaking it into fragments, some of which might be lost, this is managed by inverting a small crucible over the top of the parting glass while full of water, suddenly inverting it, when the cornet falls gently down through the water into the crucible. The water is then let off; the crucible is dried and heated to redness in a muffle, when the cornet, which as it left the mattrass was a brown, spongy, brittle mass, shrinks in every direction, becomes firm, regains its metallic lustre, and when fully red hot has all the appearance of pure gold; it has a beautiful lustre, and is soft and flexible. The gold is accurately weighed, and the process is finished. This weight indicates the absolute quantity of metal in the assayed sample. The difference between the weight of the button after cupellation, (deducting the silver added,) and the first sample, is the weight of the copper or other base metal in the gold; and the difference between the gold cornet together with the silver added, and the button after cupellation, is the quantity of silver alloyed with the gold. The silver left in solution after parting is usually recovered by immersing in it, when collected in quantity, some bright copper plates, which dissolve, and precipitate the silver in its metallic form.

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[1] When, as the last portions of lead separate, the button seems agitated by a rapid movement, by which it is made to turn on its axis. [illegible] of silver and other metals under the action of a strong heat is known by a peculiar name.

[2] Aikin, "Chemical Dictionary," our chief authority in this article.

The composition of an alloy of gold is sometimes roughly estimated by the use of the *touchstone*, a hard black stone, formerly obtained from Lydia, in Asia Minor; but black basalt answers the purpose. A number of touch-needles are formed, as in the case of silver, the first consisting of pure gold, the second of 23 of gold and 1 of copper, the third of 22 of gold and 2 of copper, and so on. The assayer selects one of these needles, rubs it upon the touchstone, and the streak produced is red in proportion to the quantity of copper in the alloy. The metal to be assayed is also rubbed, and if its streak correspond with that made by the needle, its composition is approximatively known. Several needles may be tried, until the streaks correspond. The judgment may further be assisted by moistening the streaks with nitric acid, which acts upon the copper or silver, but does not attack the gold.

English assayers have long been accustomed to report the fineness of the precious metals by a cumbrous and artificial method, which we do not describe, since the *decimal* method employed in other countries was a few years ago introduced by Sir John Herschel at the Mint. By this method fine silver is termed 1000, and the report upon any sample of alloy indicates the number of parts of pure silver in 1000 contained in it. English standard silver, for example, contains in 1000 parts of alloy 925 of silver, and 75 of copper. French standard contains in 1000 of alloy 900 of silver, and 100 of copper. English standard would therefore be reported as 925, French standard as 900. In the case of gold, the assayer terms the arbitrary weight of the alloy on which he operates 1000, and his weights are subdivided so as to give the value of the alloy in 1000ths of this quantity; so that if a portion of the alloy which originally weighed 1000 of these arbitrary units yield a quantity of gold equal to 916·6, he would report it as 916·6: 1000 ounces of such an alloy would contain 916·6 ounces of fine gold.

The assay of silver by cupellation may vary as much as 2 parts in 1000, even under a practised assayer, hence the *humid process*, as it is called, is now adopted, since it admits of an accurate estimate of the value of an alloy to within 0·5 in 1000. [See SILVER.] It depends on the precipitation of the silver in the form of an insoluble chloride, and the measurement of the amount of a standard solution of common salt (chloride of sodium) required to produce the complete precipitation of the silver in a given weight of the alloy.

The assay of the precious metals requires care rather than chemical skill, on account of the perfection of the processes, and of the very few alloys which exist. The principal alloy of silver is that with copper, this metal conferring hardness. The proportion of copper in the *standard* silver used for the coinage of different countries varies. In England it is 7·5 per cent.; in France, 10 per cent.; and in Prussia, 25 per cent. There is some difficulty in preparing standard silver, on account of a kind of *liquation* which the alloy undergoes when solidifying. When cast into ingots, the interior portions differ somewhat in composition from the outside. In bars which contain a larger proportion of silver than 719 in 1000 of alloy, the central portions are richer than the surface, but in alloys of lower value the proportion of silver is greater on the surface.

The most useful alloy of gold is also that which is [illegible] with copper; it is much more fusible than pure gold, but less ductile and malleable. English standard gold contains 8·33 per cent. of copper, or 11 parts of gold to 1 of copper. The standard gold of France contains 10 per cent. of copper. Jeweller's gold often contains silver in addition to copper.

Assaying now generally includes the determination of the quantity of some particular metal in an ore or mixture of the baser metals, such as the determination of the quantity of copper in the ore of that metal, with a view to ascertain the quantity which ought to be produced in smelting, and also, whether it would repay the smelter to work it. An assay may be conducted entirely by the *dry way*, or merely by heat with the assistance of fluxes; or by the *moist way*, in which acids or other re-agents are employed. In some cases both methods are used. The best treatise on the subject is Berthier's *Traité des Essais par la Voie Sèche*: Paris, 1834. There is also a treatise in English, by Mitchell, partly founded on the above, for the use of metallurgists, captains of mines, and assayers in general: London, 1846. See also Phillips's *Manual of Metallurgy*, and an essay in French, by Chaudet, on the assay of gold and silver.

ATMOSPHERE. See Air, Anemometer, &c.

ATMOSPHERIC RAILWAY. See Railway.

ATOM. ATOMIC THEORY. The word atom is derived from the Greek word ἄτομος, indivisible. Although matter is capable of being divided to an extent far beyond our powers of conception, yet it is very probable that there is a limit in nature, beyond which it is incapable of further subdivision. Supposing this limit to be attained, the minute particles of matter are then termed *atoms;* they are incapable of being further divided, and upon this property is founded one of the most beautiful doctrines of modern chemistry, a doctrine upon which the precision and consequent advance of this comprehensive science have mainly depended,—namely the Atomic Theory.

In every compound, whether formed artificially or by the hand of nature, the component parts always exist in the same relative quantities. Pure water, at all times and in all places, contains in every 100 parts 11.111 hydrogen, and 88.889 oxygen; marble always contains 56 parts of lime and 44 of carbonic acid, per cent.; common salt always contains 40 parts of sodium and 60 of chlorine, per cent. If, in forming these substances artificially, any one of the constituents be in excess, combination will still take place, but the excess will be rejected.

If, instead of considering the composition of the above-named substances by the per centage of their constituents, we take the smaller numbers that will represent their composition, then we say, that 1 atom of hydrogen weighing 1 + 1 atom of oxygen weighing 8 = 1 atom of water weighing 9. Or 1 atom of lime weighing 28 + 1 atom of carbonic acid weighing 22 = 1 atom of carbonate of lime weighing 50. Again, 1 atom of sodium weighing 24 + 1 atom of chlorine weighing 36 = 1 atom of chloride of sodium weighing 60. The meaning which is to be attached to the term *weight* in these examples will be explained presently.

Now the atomic theory is based upon the proposition, that matter is capable of being reduced to atoms which do not admit of further division, and that the atoms of one kind of matter, which in the same substance have all the same size and weight, combine with the atoms of a different kind of matter, only in certain invariable ratios. It follows from this, that when two kinds of matter combine to form a compound, they combine atom to atom, for in order to combine chemically, the two bodies must be reduced to their state of greatest division, so that the respective atoms may be free to come within the range of each other's attraction. In such cases, an atom of one kind combines with an atom of the other kind. It cannot combine with half an atom, because no such thing exists, and it cannot combine with two atoms, because its attraction is satisfied with one. The two dissimilar atoms thus combined, now form a single compound atom, which in its turn is incapable of further division, for the very act of division is destruction, as far as the compound is concerned. Hence it will be seen, that, according to this theory, a simple atom is incapable of further division; a compound atom is capable of being divided into two simple atoms, but in such case, the compound ceases to exist. This obvious illustration explains, in a beautiful manner, the immutable nature of compound bodies, as they exist in nature or in art. If, for example, 1 grain weight of one kind of matter, consisting of 100 atoms, were combined with 1 grain weight of another kind of matter, also consisting of 100 atoms, the resulting compound would be homogeneous or of the same nature throughout; a substance would be formed possessing different properties from those of its constituents, and consisting of 100 compound atoms. If, however, to form the same substance, 1 grain or 100 atoms of the one kind of matter were presented to 2 grains or 200 atoms of the other kind of matter, the same compound would be formed, but the excess of 100 grains would be rejected, or be mechanically mixed with the compound.

Now if we suppose matter to be capable of infinite division, that atoms were in fact divisible, there is no sufficient reason why bodies should not combine in all proportions. The one hundredth of a grain in the above example, ought, in such case, to combine with the half hundredth, or the quarter hundredth, or any other proportional of a grain of the other substance, so as to form an infinite number of compounds, all possessing different properties to each other and to those of their constituents. That bodies do not combine in this indefinite manner, is a strong argument in favour of the atomic theory.

In the above remarks it has been supposed that dissimilar bodies combine only atom to atom. The real fact is, that an atom of one kind of matter may combine not only with 1 atom of another kind of matter, but with 2 atoms, with 3 atoms, or more, producing in each case compounds with distinct properties. Combinations of this kind have been explained on one of two suppositions. 1. Suppose an atom of A to combine with an atom of B, to form a certain compound; in such case, the affinity of A for B may be so far unsatisfied, that an attraction may exist for another atom of B. Should the conditions be favourable for this combination, a second atom will combine with A, producing a compound with new properties; a third atom of B may also combine with A, forming a third distinct compound. 2. Instead of supposing the simple atom A to have a distinct attraction for 1, 2, or 3 atoms of B, we may suppose that the compound atom A + B may exert an attraction for a second atom of B, and form a compound represented by A + 2 B, and that this, in its turn, may attract a third atom of B, forming A + 3 B, and so on.

For example, 32 parts of zinc combine with 8 parts of oxygen, to form 40 parts of oxide of zinc, and the affinity then seems to be satisfied: no further attraction seems to exist between these bodies; but if another portion of oxygen could be absorbed by the zinc, so as to form a second oxide, it would be another 8 parts, neither more nor less, and the deutoxide of zinc would consist of 32 zinc + 16 oxygen.

Again, 100 grains of mercury combine with 4 grains of oxygen, so as to form protoxide of mercury. As the combination is atom to atom, it has been supposed, in this, as in other similar cases, that there are as many atoms in 100 grains weight of mercury, as there are atoms in 4 grains weight of oxygen. But in this case, the affinity is not satisfied; an additional quantity of oxygen can be combined with the same quantity of mercury; an atom of mercury has an attraction for two atoms of oxygen, or 100 grains of mercury will combine with 8 grains of oxygen, and the second oxide contains twice as much oxygen as the first. If a third oxide were to be formed with 100 grains of mercury, it would contain not 9, nor 10, nor 11, but exactly 12 grains of oxygen. Thus molybdenum combines with oxygen in this way, forming three distinct oxides: the first oxide consists of 1 atom of the metal + 1 atom of oxygen; the second oxide contains one atom of the metal + 2 atoms of oxygen; and the third consists of 1 atom of the metal + 3 atoms of oxygen.

In these, and all such examples, it is of no consequence which of the combining substances be taken as the constant quantity; 100 of A may unite with 50 of B, or with twice as much, namely 100, or with thrice as much, namely 150; or, what is the same thing, 100 of B, may unite with 200 of A, or with half as much, or one third as much, for it will be observed, that the multiple ratio affects one kind of matter as much as it affects the other.

Gaseous bodies, which have a chemical action on each other, also unite in the same definite manner. For example, the proportions of oxygen that combine with any quantity of nitrogen to form compounds, will be to each other as the numbers 1, 2, 3, 4, 5, and never to any intermediate numbers. But instead of taking gases by weight, we may take them by bulk or volume, and they will be found to combine in the most simple ratios, the ratio being as 1 to 1, 1 to 2, or 1 to 3. Thus 1 volume of oxygen requires exactly 1 volume of hydrogen to form the deutoxide, and 2 volumes to form water. 1 volume of hydrogen requires 3 volumes of nitrogen, to form ammoniacal gas, and so on.

Hence the law of combination may be thus concisely expressed:—When a body A combines with a body B in several proportions, the numbers expressing these proportions are integer multiples of the smallest quantity of B that A can absorb. The law may be also thus expressed:—When two bodies combine in several proportions, the first proportion is either a multiple or a submultiple of all the rest.

These laws of definite proportions, and of the atomic theory in reference to weights and volumes, are well illustrated by the compounds of nitrogen and oxygen: these bodies unite with each other in 5 proportions, and in the simplest ratios, forming three oxides and two acids.

	Atoms or equivalents of Nitrogen and Oxygen	Weights of the atoms or equivalents of Nitrogen and Oxygen	[illegible]	Volumes of Nitrogen and Oxygen	[illegible]
	N. O	N. O.		N. O.	
1 atom of the Protoxide of Nitrogen consists of	1 + 1	14 + 8	22	1 + 0.5	1
1 atom of the Deutoxide of Nitrogen	1 + 2	14 + 16	30	1 + 1	2
1 atom of the Nitrous Acid	1 + 3	14 + 24	38	1 + 1.5	
1 atom of the Peroxide of Nitrogen	1 + 4	14 + 32	46	1 + 2	1
1 atom of the Nitric Acid	1 + 5	14 + 40	54	1 + 2.5	

In the above examples the oxygen combines in regular arithmetical progression. This, however, is not always the case. The law of multiple ratios simply requires, that the proportionals shall all be multiples of the smallest. Thus, in the known compounds of chlorine and oxygen, the oxygen combines by weight or volume, with a weight or volume of chlorine, according to the numbers 1, 3, 4, 5, 7. Should any intermediate compounds be discovered, the oxygen will be in the proportion of 2 and 6; such compounds may, however, be impossible.

It is necessary to attach a precise meaning to the term *weight*, or *combining weights*, when speaking of the union of chemical elements. Thus we say, that water is composed of 8 parts by weight of oxygen, and 1 part by weight of hydrogen. In such case, 8 is called the *equivalent* or *combining weight* of oxygen, and 1, the equivalent or combining weight of hydrogen, and 8 + 1 = 9, is the equivalent or combining weight of water. But we may also represent hydrogen by 100, or by 1000, or any other number, provided all the numbers be multiplied in an equal ratio; or hydrogen may be represented by $\frac{1}{100}$, or $\frac{1}{1000}$, if all the other numbers be equally reduced. If hydrogen were represented by 100, oxygen would be 800, and nitric acid 5.400. Or if hydrogen were 0.01, oxygen would be 0.08. It is the ratio that gives value to these numbers. When we say that 40 parts sulphuric acid saturate 48 parts potash, there is nothing in these numbers of any particular value; for 20 and 24, 5 and 6, would do as well, these numbers being in the same ratio as 40 and 48, and this is the ratio between the sulphuric acid and the potassa; but as small numbers are more easily remembered than large ones, it is an object to reduce the equivalent numbers to the lowest ratio that can be obtained.

Berzelius assumes oxygen as = 100, other chemists have taken oxygen as = 1, in which case the whole scale of equivalent numbers must be reduced to one eighth of what they would be when hydrogen is = 1. Thus sulphuric acid, which in the hydrogen scale = 40, would in the oxygen scale = 5; nitric acid, instead of being 54, would be 6.75; lime, instead of being 28, would be 3.5; carbonic acid, instead of 22, would be 2.75; and hydrogen would be 0.125. Nearly one half of the ascertained numbers would be fractional. Dr. Thomson gives the following reasons for preferring the oxygen scale: "Hydrogen, so far as we know at present, combines with but few of the other simple bodies; while oxygen unites with them all, and often in various proportions. Consequently, very little advantage is gained by representing the atom of hydrogen by unity; but a very great one by representing the atom of oxygen by unity; for it reduces the number of arithmetical operations respecting these bodies, to the addition of unity; and we see at once, by a glance of the eye, the number of atoms of oxygen which enter into combination with the various bodies."

In the *tables of equivalents*, as they are called, which have been constructed with great care by first-rate chemists, the quantity, but not the quality, of the weights is given. It is not stated whether these weights are grains, or ounces, or pounds. In the laboratory, or in the chemical manufactory, it may be any one of them, or it may be hundred-weights or tons. In theory, however, a very different denomination is implied. When it is stated, that potash consists of 40 potassium + 8 oxygen, these numbers are referred to the unit by which all elementary bodies are measured; this unit is hydrogen, and its equivalent number, or combining weight, is 1.

Dr. Dalton was the first who conceived clearly the idea, that from the relative actual weights of the elements in the mass of any compound body, the relative weights of the ultimate atoms of bodies might be inferred. Water, he conceived, consisted of 1 part by weight of hydrogen, and 8 parts by weight of oxygen, and he supposed that when two combinations of two bodies could be obtained, that the first must be composed of an atom of each, and the second, of 2 atoms of the one, and 1 atom of the other. Applying this reasoning to the compound of oxygen and hydrogen, he supposed that 1 atom of hydrogen + 1 atom of oxygen formed water, and hence that the weights of the atoms must be in the same ratio as the weights of the total quantities that compose water. In this way he examined a large number of compounds, assuming the weight of hydrogen as unity, and from that determining the weight of the atoms of other elements by representing them as so many times heavier than the atom of hydrogen, the number of times being discovered by comparing the weights of different elements. These weights were determined by the analysis of the compounds formed either with one part hydrogen, or with a given weight of some other element whose relative atomic weight to that of hydrogen had been ascertained. In this way the weights of the atoms of other bodies were expressed in atoms of hydrogen, each of which was denoted by unity.

The atomic weight of one body being thus arbitrarily fixed, the atomic weights of other bodies were found in the following manner. 100 parts of water contain, according to analysis, 11.111 hydrogen and 88.889 oxygen. Assuming that in the composition of water every atom of hydrogen is combined with 1 atom of oxygen, then the weight of 1 atom of hydrogen = 11.111 : 88.889 = 1 : 8 and this last number is the atomic weight of oxygen.

100 parts of sulphuretted hydrogen contain 5.9 parts of hydrogen and 94.1 parts of sulphur. Assuming that this compound contains equal numbers of atoms of hydrogen and sulphur, we have the proportion 5.9 : 94.1 = 1 : 16; or the atomic weight of sulphur is 16, if that of hydrogen be assumed as = 1.

On examining the relation of sulphur to oxygen, we find that 100 parts of sulphurous acid contain 50 of sulphur and 50 of oxygen; and 100 parts of sulphuric acid 40 sulphur and 60 oxygen. Now 50 : 50 = 16 : 16, and 40 : 60 = 16 : 24; and since the atomic weight of sulphur is 16, that of oxygen 8, we may conclude, that in sulphurous acid, 1 atom sulphur = 16, is combined with 2 atoms oxygen = 16, and in sulphuric acid with 3 atoms oxygen = 24.

Carbonic oxide contains 6 parts carbon combined with 8 oxygen; and carbonic acid 6 carbon with 16 oxygen. The atom of carbon is estimated at 6, supposing that in carbonic oxide it is combined with 1, and in carbonic acid with 2 atoms of oxygen.

Sulphuret of carbon contains 6 parts carbon united with 32 sulphur; therefore, 1 atom of carbon with 2 atoms of sulphur.

In ammonia 14 parts of nitrogen are combined with 3 of hydrogen; therefore, 1 atom of nitrogen with 3 atoms of hydrogen.

In the yellow oxide of lead, 103.8 lead are combined with oxygen; the atomic weight of lead may therefore be estimated at 103.8. Galena is a compound of lead and sulphur, in the proportion of 103.8 : 16, and this compound must be regarded as containing equal numbers of atoms of its elements.

In this way the atomic weight of hydrogen being assumed = 1, the following atomic weights have been determined; oxygen 8, sulphur 16, carbon 6, nitrogen 14, lead 103.8. In a similar manner the atomic weights of other elements have been calculated, as set forth in the following table:—

LIST OF ELEMENTARY BODIES, WITH THEIR ATOMIC WEIGHTS AND SYMBOLS.

Element.	Symbol.	Equivalent. Number. H = 1	O = 100
Aluminium	Al.	13·72	171·17
Antimony (Stibium)	Sb.	129·03	1612·90
Arsenic	As.	75	[illegible]
Barium	Ba.	68·64	855·13
Bismuth	Bi.	21[illegible]	26[illegible]·5
Boron	B.	10·9	1[illegible]
Bromine	Br.	78·27	978·3
Cadmium	Cd.	55·74	696·76
Calcium	Ca.	20·12	251·4
Carbon	C.	6·	75
Cerium	Ce.	46·	575
Chlorine	Cl.	35·41	442·62
Chromium	Cr.	26·27	328
Cobalt	Co.	29·5	368·
Copper (Cuprum)	Cu.	31·65	395·6
Didymium	D.	48·	600·0
Erbium	E.	...	
Fluorine	F.	19·	235·5
Glucinum	G.	6·97	87·1
Gold (Aurum)	Au.	98·33	1229·
Hydrogen	H.	1	12·5
Ilmenium	Il.	...	...
Iodine	I.	126·88	1586·0
Iridium	Ir.	99·?	12[illegible]
Iron (Ferrum)	Fe.	28·04	350·5
Lanthanum	La.	...	...
Lead (Plumbum)	Pb.	103·57	1294·64
Lithium	L.	6·53	81·66
Magnesium	Mg.	12·66	158·33
Manganese	Mn.	27·57	344·68
Mercury (Hydrargyrum)	Hg.	100·10	1251·29
Molybdenum	Mo.	47·96	599·1
Nickel	Ni.	29·54	369·33
Niobium	Nb.	...	
Nitrogen	N.	14	175·0
Osmium	Os.	99·41	1242·62
Oxygen	O.	8	100
Palladium	Pd.	53·24	665·47
Phosphorus	P.	32·02	400·3
Platinum	Pt.	98·68	1233·5
Potassium (Kalium)	K.	39·1	487
Rhodium	R.	52·16	652·13
Ruthenium	Ru.	52·11	651·39
Selenium	Se.	39·62	495
Silicon	Si.	21·35	266·8
Silver (Argentum)	Ag.	108·0	1350
Sodium (Natrium)	Na.	22·97	287·17
Strontium	Sr.	43·84	548·02
Sulphur	S.	16·0	200·0
Tantalum (*Columbium*)	Ta.		
Tellurium	Te.	64·14	801·76
Thorium	Th.	...	...
Titanium	Ti.	25·5	313·8
Tin (Stannum)	Sn.	58·82	735·29
Titanium	Ti.	24·12	301·55
Tungsten (*Wolfram*)	W.	94·64	1183·0
Uranium	U.	60·0	750·0
Vanadium	V.	68·46	855·84
Yttrium	Y.		
Zinc	Zn.	32·52	406·59
Zirconium	Zr.	33·58	419·73

N.B.—The names printed in italics are those of rare and comparatively unimportant metals. Those elements to which no numbers are attached have not been sufficiently studied to enable the chemist to give their combining proportions.

In this table the elementary substances whose names are printed in Italics, have not yet been examined with sufficient care to determine their atomic weights.

In the preceding details the combining ratio is stated as always consisting of 1, 2, 3, 4, &c to 1. In some works on Chemistry we find ratios which appear to contradict this law. Thus the sesquioxide of iron is said to consist of 1 atom of iron, with 1½ atom of oxygen; but as half atoms involve a contradiction of terms, it is usual to get over the difficulty by doubling the numbers, so as to make 1 atom of sesquioxide of iron to consist of 2 atoms iron, and 3 of oxygen.

Another supposed difficulty in the way of the atomic theory has been in such combinations as sulphuric acid and water, alcohol and water, in which the existence of determinate ratios is indistinct, for these substances appear to combine in all proportions. Such too is the case with the alloys of metals. But it generally happens that where bodies appear to combine in all proportions the affinity is weak; the compound is really not a new substance possessing properties peculiar to itself, and which distinguish it from every other substance in nature; but the compound possesses most of the characters of a mixture; its properties form a mean between those of its constituents, in which the distinctive properties of each constituent can be recognised with greater or less distinctness.

After all, the doctrine of definite proportions may only be a mere expression of facts essentially different from the real atomic constitution of bodies. Nevertheless, it is a true theory, inasmuch as it generalizes the innumerable facts of chemistry, and inscribes them in a sort of short-hand, which is as remarkable for its simplicity as for the truth of its indications.

AUGER. AWL. These are instruments for boring wood, of which there are a great number of varieties. The *brad-awl* is the simplest. It consists of a cylindrical wire with a chisel edge, Fig. 78. It is sometimes sharpened with three facets as a triangular prism. The awl used by wire-workers, such as bird-cage makers, &c. Fig. 79, is square and sharpened at all its edges, and tapers off very gradually until near the point, where the sides meet rather more abruptly. Tools of this kind displace rather than remove the material which they penetrate.

Fig. 78.

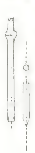


Fig. 79.

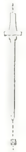


Fig. 80.

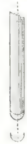


Fig. 81.

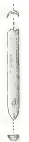


Fig. 82.

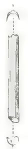
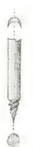


Fig. 83.



Most of the boring instruments used in carpentry are fluted, in order to give room for the shavings. The *shell-bit*, Fig. 80, also called the *gouge-bit* and *quill-bit*, is sharpened at one end like a gouge, and when revolving it shears the fibres of the wood round the margin of the hole, and removes the wood almost as a solid core. Very small tools of this kind are used for boring holes in some kinds of brushes.

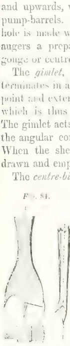
The *spoon-bit*, Fig. 81, is generally bent up at one end, so as to make a taper point. It acts something like a pointed drill, but has a keen edge suitable for wood. The *cooper's dowel-bit*, and the *table-bit* for making holes for the wooden joints of tables, are of this kind. When the end is bent into a semicircular form, it is called a *duck nose-bit* from its resemblance, and a *brush-bit* from the use to which it is applied.

The *nose-bit*, *slit-nose-bit*, and *auger-bit*, Fig. 82, is slit up a small distance near the centre, and the larger piece of the end is then bent up nearly at right angles to the shaft, so as to act like a paring chisel, and the corner of the reed near the nose also cuts slightly. On a large size this tool is called the *shell-auger*, and is sometimes made 3 inches in diameter and upwards, with long movable shanks for boring pump-barrels. Before using nose-bits a preparatory hole is made with a brad-awl or centre punch; with augers a preparatory hole is always made with a gouge or centre bit of the same size as the auger.

The *gimlet*, Fig. 83, is also a fluted tool, but it terminates in a sharp worm or screw, beginning as a point and extending to the full diameter of the tool, which is thus drawn by the screw into the wood. The gimlet acts like an auger, by cutting the wood by the angular corner between the worm and the shell. When the shell is full of wood the gimlet is withdrawn and emptied.

The *centre-bit*, Fig. 84, consists of three parts, viz. a centre point or *pin*, which serves as a guide; a thin shearing point or *nicker*, which cuts through the fibres like the point of a knife; and a broad chisel edge or *cutter*, placed obliquely, to pare up the wood within the circle marked out by the point. The cutter should have a little less radius, and less length than the nicker. There are many forms of centre-bits described in Mr. Holtzapffel's excellent work, which ought to be in the hands of every practical and amateur mechanic, whether in wood or metal.

Fig. 84.



Various forms of auger are made with spiral stems, so that the shavings may ascend the hollow worm, and thus save the trouble of withdrawing the bit so frequently. The *twisted gimlet*, Fig. 85, is a tool of this kind. It is made with a conical shaft, round which is filed a half-round groove, one edge of which is thus sharpened, and gradually enlarges the hole after the worm has penetrated, and being smaller than in the common gimlet, there is less risk of splitting. The common *screw auger*, Fig. 86, is forged as a parallel blade of steel, and twisted while red-hot. The end terminates in a worm, by which the auger is gradually drawn into the work. The same kind of shaft is sometimes made with a plain conical point, with two scoring cutters and two chisel edges, forming a sort of double centre-bit.

Fig. 85.

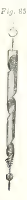
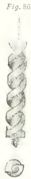


Fig. 86.



The various kinds of boring bits are usually set in motion by means of the carpenter's brace, one end of which receives the bit, and the other end, consisting of a swivelled head or shield, is pressed forward horizontally by the chest of the workman. Augers are usually moved by transverse handles. Some augers are made with shanks, and are riveted into the handles like the common gimlet; the most common method is to form the end of the shaft into a ring or eye, through which the transverse handle is tightly drawn. Brad-awls and similar tools requiring only a slight force have straight handles.[1]

Mr. Richardson[2] states on the authority of Junius, that the word awl has the same origin with *eel*, and was so called because it can introduce and insinuate itself like an eel.

AUTOMATON, from **αὐτὸς** and **μάομαι**, a *self-moving* machine, or one so constructed, that by means of internal springs and weights or other well known contrivances, it may move for a considerable time as if endowed with life. According to this definition, clocks and watches are automata; indeed, the term *automatic machinery* has of late years been applied to the self-acting looms and other machines which are now so extensively used in the manufactures of this country.

Many early writers delight in narratives of wonderful toy automata, but as they have not stated the mechanical contrivances by which the results were brought about, it is of no use to repeat them here. As an example of the small degree of reliance which can be placed on these narrations, we may refer to the wooden eagle of John Müller of Nuremberg, commonly called Regiomontanus, which flew forth from the city of Nuremberg aloft in the air, and met the emperor Maximilian as he was approaching the city; having saluted him, the bird returned with him to the city gates. This story is gravely related by such eminent authorities as Kircher, Porta, Gassendi, Lana, and Bishop Wilkins, but unfortunately for the truth of it, they do not agree in their dates. Some say it was in the time of Maximilian, others in the time of his grandson Charles V., who was born 64 years after the death of Müller. The same philosopher is also said to have made an iron fly, which at a feast, flew forth from his hand, and taking a round, returned thither, to the astonishment of the guests. This, if true, was probably some kind of magnetic trick.

In approaching more modern times, our information is more precise, and the automata are less marvellous. The best examples are those by Vaucansen, Camus, Kempelen and others, and are described by Sir David Brewster in his entertaining little work on Natural Magic. The Automaton

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(1) Holtzapffel. "Turning and Mechanical Manipulation," vol. ii.

(2) A New Dictionary of the English Language, by Charles Richardson. London, 1839.

Chess-player of Kempelen was a clever hoax, and the inventor himself was really ashamed at its success. A full history and description of this machine, if such it may be called, is given by the editor in his "Amusement in Chess," London 1845. A few years ago, the editor saw in a watch-maker's room at Geneva, a small automaton, which he believes was invented by M. Maillardet, a clever mechanical artist of the last century. It consisted of a small nest about 3 inches in diameter. On touching a spring, a bird of beautiful plumage, not larger than a small humming-bird, started up and perched on the edge of the nest, fluttering its wings and opening its bill with the tremulous vibration peculiar to singing birds. It then began to warble a rapid succession of notes similar to the song of the nightingale, and loud enough to be heard over the whole room. It then suddenly darted down into its nest, and the nest closed upon it. The song continued about four minutes, and the exhibitor stated that the bird warbled several different strains. We learn from Dr. Brewster,[1] that the great variety of notes was not produced by a corresponding number of pipes, for which there was evidently no room, but the artist ingeniously managed to have only one pipe, the vacuity of which is shortened or lengthened by a piston working inside, and thus producing sounds graver or more acute according as the machinery operates upon it.

The automaton which has, perhaps, received most attention is the speaking machine. A speaking automaton was constructed by Kempelen, and has received further improvements from professors Willis and Wheatstone. A machine of this kind, constructed by a German, was exhibited a few years ago at the Egyptian Hall in London. We cannot say that it was successful.

AXIS, a word used in various senses in different departments of science, in which case it is connected with other terms which give it a special meaning and application. Thus we speak of the *axis of inertia*, *of rotation*, *of refraction*, *of polarisation*, &c. When used by itself, the term generally refers to the axis of rotation or of symmetry. Thus, when a body has a motion of rotation or revolution, the line round which it rotates or revolves is called the *axis*. So also a line, on both sides of which the parts of a body are similarly disposed, extending as far in one direction as in the other, and in exactly opposite directions, is called the *axis of symmetry*.

The mechanical properties of the axis of rotation are of great importance. In some cases, when the body revolves, the axis itself is movable and in actual motion, as in the earth, the planets, a common spinning top, &c., but generally in mechanics the axis is immovable, or may be regarded as such, as in wheel work, the moving parts of watches and clocks, turning-lathes, mill-work, hinges, &c. Where the axis, or pivot, or joint is not fixed, it may be considered so in reference to the mechanical effect, as in scissors, shears, pincers, &c.

In cases where wheel-work is concerned, the body generally turns continually in the same direction, each of its points describing a complete circle during every revolution of the body round its axis; but in some cases the motion is alternate or reciprocal, as in the pendulums of clocks, the balance-wheels of chronometers, the treadle of a lathe, doors or lids on hinges, scissors, pincers, &c. When the alternation is constant and regular, as in pendulums and balance-wheels, it is called *oscillation* or *vibration*.

When a solid body is movable on a fixed axis, it is susceptible of motion only by rotating on that axis. If it be subjected to the action of instantaneous forces, one or other of the following effects will be produced:—1. The axis may resist the forces and prevent any motion. 2. The axis may modify the effect of the forces, thereby sustaining a corresponding *percussion*, and the body receiving a motion of rotation. 3. The forces may cause the body to rotate round the axis even were it not fixed, in which case the axis will suffer no percussion.

If instead of instantaneous forces, the body be subject to continuous ones, similar effects will be produced, only instead of percussion we get pressure. But "the impressed forces are not the only causes which affect the axis of a body during the phenomenon of rotation. This species of motion calls into action other forces depending on the inertia of the mass, which produce effects upon the axis, and which play a prominent part in the theory of rotation. While the body revolves on its axis, the component particles of its mass move in circles, the centres of which are placed in the axis. The radius of the circle in which each particle moves, is the line drawn from that particle perpendicular to the axis. A particle of matter having a circular motion is attended with a centrifugal force proportionate to the radius of the circle in which it moves and to the square of its angular velocity. When a solid body revolves on its axis, all its parts are whirled round together, each performing a complete revolution in the same time. The angular velocity is consequently the same for all, and the difference of the centrifugal forces of different particles must entirely depend upon their distances from the axis. The tendency of each particle to fly from the axis arising from the centrifugal force is resisted by the cohesion of the parts of the mass, and in general, this tendency is expended in exciting a pressure or strain upon the axis. This pressure or strain is, however, altogether different from that already mentioned, and produced by the forces which give motion to the body. The latter depends entirely upon the quantity and directions of the applied forces in relation to the axis; the former depends on the figure and density of the body and the velocity of its motion."

These very complex effects do not readily admit of popular exposition; but the reader who is interested in the subject, will find it treated in a lucid manner in the tenth chapter of Dr. Lardner's Mechanics, in the Cabinet Cyclopædia.

AXLE. See WHEEL CARRIAGES.

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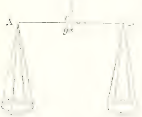
[1] Edinburgh Encyclopædia, vol. [illegible] [illegible].

BAKING. The process of drying and consolidating a substance by means of heat. [See BREAD, BISCUIT, POTTERY, PORCELAIN, SUGAR, &c.]

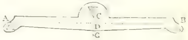
BALANCE. An instrument for ascertaining the weight of substances. It is of extensive use in the common affairs of life, in the arts, and in experimental science. It consists essentially of a lever of the first kind, in which the fulcrum is between the power and the weight to be raised. This lever, called the *beam*, A B, Fig. 87, has its fulcrum or axis of motion *c* in the centre, so that the two arms, A C, C B, are equal. The two extremities of the beam, called the *points of suspension*, support the scale-pans, one of which is for the weights and the other for the substance to be weighed: *g* is the centre of gravity of the beam, and is situated a little below the fulcrum, for if situated in that point, the beam, instead of always being horizontal when the arms are in equilibrium, would rest indifferently in any position; and if the centre of gravity were above the centre of motion, the least disturbance would cause the beam to upset. The points of suspension should be situated so that a straight line A B joining them is perpendicular to the line of symmetry formed by joining the centre of gravity *g* with the centre of motion *m*. The direction of the line *m g* is indicated by a slender pointed needle or tongue, rising perpendicularly above or below the beam: a graduated scale or arc behind it shows the deviation of the tongue from the perpendicular, and renders sensible the slightest motion of the beam. When the needle points to the zero line of the scale, which is also in the vertical of the centre of gravity, the beam must be horizontal. By means of this index we can also ascertain whether equilibrium has been attained, without waiting until the beam has ceased to oscillate; for, if it be really in equilibrium, the needle will describe equal arcs on the graduated scale on each side of the zero point, but, if there be not equilibrium, the needle will move through a larger number of degrees on one side of the zero point than on the other.

Fig. 87.



In a perfect balance, all the parts ought to be symmetrical with the centre of gravity; that is, the parts on either side of this point ought to be exactly equal in every respect. But such perfection cannot be attained in practice; the most skilful workman cannot make the two arms perfectly equal; but he approaches this state of perfection as closely as possible. In order to reduce the friction on the axis, the beam is made as light as is consistent with perfect inflexibility. To diminish the extent of surface in contact with the axis, the beam is supported on two sharp edges of tempered steel, c, Fig. 88, lying in the same straight line, and supported on two planes of steel or agate, finely polished, and placed with the greatest care in the same horizontal plane.

Fig. 88.



The scale-pans are also suspended on knife-edges A B: G is the centre of gravity of the whole beam. D is the point of coincidence of A B and C G.

Equality in the length of the arms can be tested in two or three ways. If the balance with its pans vibrate freely, and rest in a horizontal position, and after changing the pans from one end to another the balance again rests horizontally, the arms are almost sure to be equal. Or by changing the weights from one pan to another, if equilibrium be still retained, the lengths of the arms are equal.

The weights are usually of brass; but the smaller ones should be of platinum, which is not liable to oxidation or corrosion; and the weights made of this metal can be cleaned from dirt by a slight wiping, or by momentary exposure to the flame of a spirit-lamp. The minute weights, such as the fractions of a grain, are taken up by means of small brass pincers or forceps, as they are too small to be taken up quickly and safely by the hand. There is also danger of moisture or other extraneous matter being communicated to them by handling. The weights are furnished by the maker in sets, from 500 troy grains down to tenths and hundredths of a grain. These weights are frequently arranged in a geometrical series,—1, 2, 4, 8, 16, &c., grains—the advantage of which is that a smaller number of weights is required than in any other system; but the decimal division is convenient in practice. In this case the weights would be 1, 2, 3, 4, &c., up to 10 grains; 10, 20, 30, up to 100; 100, 200, 300, up to 1,000; 1,000, 2,000, up to 9,000. For the fractions the weights would be .1, .2, .3, &c.; .02, .03, .04, &c.; .001, .002, .003, &c. In this way the trouble of adding is avoided, for the number of weights in the scale is equal to the digits in the number by which the grains are expressed. Thus a load of 735.4 grains is counted by weights of 700 grains, 30 grains, 5 grains, and 4 tenths of a grain. In some of the modern forms of balance one arm is divided into 10 parts, and a small weight, formed of wire twisted into a fork, and weighing $\frac{1}{10}$th of a grain, placed upon one of the divisions of the arm, which thus acts as a steelyard, indicates from $\frac{1}{100}$th to $\frac{1}{1000}$th of a grain.

The accuracy of the subdivisions is tested by making up equal quantities from different weights, and comparing them together in the balance, a large weight previously compared with a standard weight of good authority being tried against 8 or 10 smaller, as the 100 grain weight against weights of 40, 30, 10, 8, 5, 4, 2, and 1; and then again from a quantity made up of several to remove some and replace them by others, as, for example, for the 30 grain weight to substitute a 10 and four 5 grain weights. The fractions of the grain should be examined in a similar manner.

In weighing for the purposes of chemical analysis, an error amounting to the thousandth of a grain might be of importance. But should the arms of the balance be unequal, a very exact result can still be obtained by the method of *double weighing* invented by Borda. To weigh a body is to ascertain how many times the weight of this body contains another weight of known value. Place the body, which we will call M, in one scale-pan, and produce equilibrium by placing in the other scale-pan some shot, or dry sand, or other substance in a state of minute division, so that very small portions may be added or subtracted, as occasion requires: by this means the needle can be brought exactly to zero, thereby indicating the horizontality of the beam. Then remove the body M, and substitute for it known weights until the beam is again horizontal. The amount of this weight will express exactly the weight of the body M, because these weights being placed under exactly the same circumstances of equilibrium as the body M produce exactly the same effect. In this way it is not only possible, but easy, to weigh truly with a false balance.

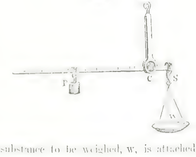
The tendency of a balance to return to and oscillate about the position of rest, after being disturbed, is called its *stability*, which is determined by the position of the centre of gravity below the point of support. Stability is far more easily attained than *sensibility*, or the tendency of a loaded balance, when poised, to turn when a very small additional weight is placed in either scale. In comparing the stability of one balance with that of another, a small amount of disturbance is given to both, such as one degree, and, if the force with which the first endeavours to recover its position be double or triple that of the second, the stability of the first is double or triple that of the second. The sensibility is ascertained by comparing the angles through which very small equal weights incline the balances. Thus, if a grain weight put into a scale-pan of each inclines one balance 4 degrees, and the other only 2 degrees, the first is twice as sensible as the second. The sensibility of a balance is also ascertained by observing the smallest additional weight that will turn it, and then comparing this addition with the whole load. Thus, if a balance have a troy pound in each scale-pan, and the horizontality of the beam varies by a small quantity, only just perceptible, on the addition of $\frac{1}{100}$th of a grain, the balance is said to be sensible to the $\frac{1}{1152000}$th part of its load, with a pound in each scale, or that it will determine the weight of a troy pound within $\frac{1}{576000}$th of the whole. One of the most sensible balances ever constructed was that employed for verifying the national standard bushel, the weight of which, together with the 80 pounds of water which it should contain, was about 250 lbs. With this weight in each scale, the addition of a single grain occasioned an immediate variation in the index of $\frac{1}{20}$th of an inch, the radius being 50 inches; so that this balance was sensible to $\frac{1}{1750000}$th part of the weight to be determined.

The sensibility of a balance is usually increased by increasing the length of its arms; by diminishing the weight of the beam; by diminishing the distance between the centres of gravity and motion; by diminishing the distance of the line joining the points of suspension from the centre of motion: the sensibility is also greater when the load is smaller.

Accurate weighing is a very difficult and delicate operation, requiring numerous precautions which the reader will find clearly stated, together with a large amount of information in the balance, weighing, &c. in the second section of Faraday's invaluable work on "Chemical Manipulation."

The ordinary weights and scales for common purposes do not require particular description, but there are various modifications of the lever of the first kind in common use, which are used as weighing machines. Such is the *Roman statera* or steelyard, Fig. 89, which consists of a beam of iron resting upon knife edges on a pivot, with one arm longer than the other. If the shorter arm with the scale be sufficiently heavy to balance the longer arm when the instrument is unloaded, the beam will, of course, be horizontal.

Fig. 89.

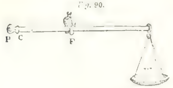


The substance to be weighed, W, is attached to a hook on the shorter arm, and a constant weight, P, is made to slide upon the longer arm, until equilibrium is established. Now, in the lever, the condition of equilibrium is that the weight W multiplied into its distance from the fulcrum, is equal to the power or counterpoise P multiplied into its distance from the fulcrum. Now as the distance of the weight from the fulcrum is constant, and the counterpoise is also constant, it is evident that in whatever proportion W is increased or diminished, the distance between P and the fulcrum must be increased or diminished in the same proportion.

In the ordinary steelyard, the centre of gravity is not at the fulcrum; so that when the weight P is removed, the longer arm usually preponderates; hence the graduation of the instrument must be commenced, not from C, but from some point between S and C. The great convenience of the steelyard is its requiring only one weight. In a pair of common scales, a load of 10 lbs. must be balanced by a weight of 10 lbs. making together a load of 20 lbs.; but in the steelyard, a weight of 10 lbs. may be balanced with only 1 lb., making together a load of only 11 lbs.

In the *Danish balance*, Fig. 90, the fulcrum F is movable, instead of the counterpoise P, Fig. 89, which, in this case, is permanently fixed at one extremity P, while the body to be weighed is placed in the scale pan at the other. If C be the centre of

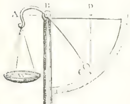
Fig. 90.



gravity of the unloaded beam, the graduation must commence from that point, because when the loop of the movable fulcrum is there, it poises the unloaded beam. By suspending from the hook at W, 1, 2, 3, &c. lbs. in succession, the divisions may be found to which the fulcrum must be removed in order to produce equilibrium, and the weight of the substance in the scale pan is indicated by the number of the point at which the fulcrum is placed when the instrument is in equilibrium.

The *bent lever balance* is made in a variety of forms, the principle of which will be understood from a common form shown in Fig. 91. It consists of a bent lever A B C, movable about an axis B. To one end of the lever, a constant weight C is fixed, and to the other end A, a hook with a scale-pan A attached, for containing the substance to be weighed. Through the centre of motion B, draw a horizontal line A B D, upon which, from A and C let fall perpendiculars; then if B A and B D are reciprocally proportional to the weights at A and C, they will be in equilibrio; but if not, the weight C will move upwards or downwards along the arc till that ratio is obtained. As the weight in W depresses the shorter arm B A, its leverage is constantly diminished, while that of the arm C B is constantly increased. When C counterpoises the weight, the division at which it settles on the graduated arc expresses its amount. The graduation, of course, commences at the point at which the index settles when there is no load in W.

Fig. 91.



[See also Weighing Machines, Weights and Measures, and Appendix.]

BALCONY. (Italian, *balco* or *palco;* French, *balcon.*) An open gallery projecting from the front of a building, and surrounded by a rail or balustrade of various devices, and supported by cantalivers, brackets or columns. A balcony may be constructed of wood, iron, or stone. Cast-iron is sometimes used, and at other times bar-iron fashioned into crail work of various figures. Balconies are generally made on a level with the sills of the windows of the first floor, and the windows are generally brought down to the floor. Sometimes a portico or porch is surmounted with a balcony, in which case the balustrade may be of stone, iron, or wood.

BALLAST. (Anglo-Saxon, *be-hlæstan*, to lade a ship.) The heavy materials, stone, gravel or iron, placed in the hold of a ship, in order to make the centre of gravity correspond with the trim and shape of the vessel, so as to be neither too high nor too low; neither too far forwards nor too far aft. The object is to lade the ship so deep that the surface of the water may rise nearly to the extreme breadth amidships. She will thus be able to carry a good sail, incline but little, and ply well to the windward. Iron ballast is alone used in the Royal Navy, but in merchantmen it is of various kinds, and masters are obliged to declare the quantity they bear, and to discharge it at certain places. Many excellent ports have been ruined by ballast being discharged in havens, roadsteads, &c. A ship is said to be *in ballast* when it has no other loading. For the regulations respecting ballast the reader is referred to McCulloch's Dictionary of Commerce, 1850.

BALLISTIC PENDULUM. See Appendix.

BALLOON. See Aërostation.

BALSAMS. The juices of certain trees and shrubs, capable of being applied to useful purposes in medicine and the arts. Balsams contain in general benzoic or cinnamic acid, with a volatile oil, and resins of variable consistency. They consequently vary in substance, thickening by degrees, and sometimes becoming entirely solid. The term balsam is by some writers confined to those juices which contain benzoic acid with a volatile oil and resin; while such as contain only resin and volatile oil are called turpentines or oleo-resins. This would exclude the balsams of Gilead, Copaiba, &c., in which there is no benzoic acid; but in ordinary language these continue to be ranked among the true balsams, the principal of which are the balsams of Peru and Tolu, benzoin, storax, and liquidamber. Peru balsam is obtained from a branching elegant tree (*Myrospermum Peruiferum*), growing in Peru, New Granada, &c., and is imported in two states, one called white, the other black. The former is the spontaneous exudation from the tree, the latter the result of boiling the bark and branches. The black balsam is the ordinary form. It is imported from Valparaiso in canisters or earthen pots, is of the consistence of treacle, and on account of its high price is extensively adulterated with turpentine, copaiba, or volatile oil. 1,000 parts genuine black balsam ought to saturate 75 parts pure carbonate of potash. Black balsam is fragrant, and is therefore employed as a perfume for pomatums, sealing-wax, lozenges, &c., and occasionally for chocolate and liqueurs. Balsam of Tolu is obtained from a closely allied species of tree, if not from the same species as that which yields Peru balsam. It has the taste and odour of the white balsam of Peru, and its constituents are the same. These balsams scarcely differ, except that in Tolu there is a facility of becoming resinified, which does not exist in the other.

Benzoin, improperly called a gum, and known as Gum Benjamin, must rank among balsams and resins. It is quite insoluble in water, and is the hardened and fragrant juice of a tree (*Styrax benzoin*, or *Lithocarpus benzoin*) growing in Sumatra, Borneo, &c. In commerce it is met with in cakes, the best of which are of a light yellowish or fawn-colour, with portions of an almond shape, whiter than the rest. This is from the younger trees, and is called *Benzoe amygdaloides*. The chief use of benzoin is in yielding benzoic acid, but it is also much employed in perfumery, and helps to give the peculiar fragrance to the incense burnt in Roman Catholic censers. It is likewise an ingredient in varnishes, for such articles as are liable to be much handled, its fragrance being evolved by the heat of the hand. For the same reason it is added to the spirituous solution of isinglass, of which court-plaster is made.

Storax belongs to the same natural family as benzoin, being the product of *Styrax officinalis*, a handsome shrub, a native of Syria, Italy, and most parts of the Levant, and common all over Greece and the Peloponnesus. The storax of commerce is obtained from Asiatic Turkey. It is procured by incisions in the bark of the tree, whence oozes a liquid resinous substance which hardens in tears about the size of peas, and these in masses, constitute the rare and valued *Styrax albus*. Various qualities are met with in commerce, but the ordinary kinds are largely adulterated with saw-dust and resin. Storax was formerly imported wrapped in a leaf under the name of reed or cane styrax, (*Styrax calamita*,) but the substance now so called is a black or brown article in powder or in grains, or in agglutinated lumps. Another kind common in the drug market is called liquid storax, and is a dark-coloured substance with a disagreeable odour, more resembling coal-tar than balsam. For medical purposes it is necessary to purify storax in alcohol, and distil before the balsam is used. There is another substance called Storax in commerce which is often confounded with this; but is the product of the *Liquidamber styraciflua*, belonging to the natural family *Balsamaceæ*. This fine tree grows in Mexico and the United States, and resembles our lesser maple. A fragrant resin exudes, but not very copiously, from incisions in the stem, and this becoming dry and opaque forms the *soft* or white liquidamber.

Among balsams or oleo-resins in which there is an absence of benzoic acid are the following. *Copaiba* or *Copaiva* Balsam obtained from various species of *Copaifera*, trees growing in South America. The balsam flows freely from the stem as a clear transparent liquid like olive-oil, but thickens afterwards. From it are prepared essential oil of copaiba, resin of copaiba, and copaivic acid, employed in medicine. The balsam is also used for making paper transparent, and for certain kinds of lacquering. *Mecca Balsam* is the produce of a shrub (*Amyris Gileadensis*) growing at Gilead in Judea. It is turbid when fresh, but becomes clear and transparent by degrees. Chinese varnish and Japan lac varnish, whose names betoken their origin, are both valuable varnishes. The former is soluble in alcohol and ether, the latter in oil.

BALUSTRADE. (Latin [illegible], a space in the ancient baths that was railed in.) A range of small columns or *balusters* supporting a cornice and used as a parapet or a screen to conceal the whole or a part of the roof. Balustrades are also employed on the margins of stairs, or before windows, or to inclose terraces or balconies by way of security; or to separate one place from another, as around altars, fonts, or on the sides of the passage way of bridges. The word is sometimes improperly spelt *balastrade*.

BANDANAS. See CALICO PRINTING.

BARBERRY. (*Berberis*.) A family of plants bearing an acid fruit, and giving its name to the natural order *Berberidaceæ*. The common barberry is a graceful shrub, well known in England as well as in most temperate climates. De Candolle speaks of it as extending from Candia to Christiana; but neither this species nor any other of the family has been met with in Africa, Australia, or the South Sea Islands. In northern latitudes the barberry affects the valleys, in southern the mountains; it is found on Mount Ætna at the height of 7,500 feet. In North and South America it is well known, and has been observed far south, near the straits of Magellan.

The fruit of this shrub is a cluster of drooping berries, of a beautiful coral red. Owing to the oxalic acid they contain, these berries are very sour, but they form with sugar an agreeable preserve, for sweetmeats, tarts, &c., and an excellent jelly. A cooling drink is made from them for invalids, and they are also pickled with vinegar, as a garnish for dishes. But it is on account of the yellow colouring matter and astringent properties of the stem and bark that the barberry has a place in our pages, for these make it useful as a dyeing material. The root is also bitter and styptic, and is used in Poland to give a yellow colour to leather. An Indian species (*Berberis tinctoria*) has a similar reputation for yielding a good yellow colouring material, and also furnishes a decoction which is said to give relief in cases of ophthalmia. The colouring matter is found in the whole of the root, but in the stem it is only deposited round the pith and near the bark; the great bulk of the woody fibre contains no colour. As the natives of India are skilful in making extracts, it has been suggested, that the colouring matter be sent to England in that form, and without the additional weight of the woody fibre. The colour is quite as good as that of the European root which we import from Cologne and Hamburg. Siberian barberry is known among the Mongol Tartars as Yellow-wood, and is applied by them to superstitious as well as medicinal uses. There are several varieties of the common barberry, differing but little in general character, but varying in the appearance of the fruit. Besides the well-known red-fruited, there are the white or yellow-fruited, the stoneless, the violet, purple or black-fruited, and the sweet-fruited, erroneously so called, for it is scarcely less acid than the common barberry, with which it agrees in the colour of the fruit, but the leaves are shining and of a brighter green. This variety is found wild in Austria.

The Barberry is interesting to naturalists on account of a remarkable property of its stamens. The irritability of these organs is such, that when the point of a pin is lightly applied to the filaments, they bend forward towards the stigma, and afterwards partially rise again. Experiments, with different powerful agents, have been tried, and it is found that this irritability is destroyed by poison. Arsenic and corrosive sublimate render the filaments too stiff and brittle to act, while prussic acid, opium, and belladonna make them too relaxed and flaccid. From these curious facts, it is inferred that there is in plants something analogous to the nervous system in human beings, and that in both cases it is more highly developed in some individuals than in others.

The barberry is infested by a minute fungus or blight, (*Æcidium berberidis,*) which fixes on the tenderest parts, and scatters, from thousands of small tubular openings, the orange-coloured dust which is so commonly seen on the leaves and flowers of this plant. This dust consists of a countless multitude of sporules, and it is their presence, doubtless, which has given rise to the idea that the barberry communicates blight to wheat fields. The *rust* which infests corn is indeed of the same colour as the barberry blight, but it is quite a different fungus, and the one can never propagate the other. Supposing, therefore, that there are any grounds for the popular opinion as to the injurious nature of barberry bushes to wheat, these are yet unexplained, and cannot be assigned to the presence of the parasite.

BARGE-BOARDS. The inclined projecting boards placed at the gable of a building, and hiding the horizontal timbers of a roof. They are frequently carved with various ornaments.

BARGE-COUPLES are two beams mortised and tenoned together for the purpose of increasing the strength of a building.

BARGE COURSE. The part of the tiling which projects over the gable of a building, and which is made good below with mortar.

BARILLA. See Soda.

BARIUM. The metallic basis of baryta. It may be obtained by strongly heating baryta in an iron tube through which the vapour of potassium is conveyed. The potassium combines with the oxygen of the baryta, and reduces the barium, which may be extracted by mercury and distilling the amalgam in a small green-glass retort. Barium is a white metal with the colour and lustre of silver; it is malleable, fuses below a red heat, decomposes water and oxidizes in the air. Its equivalent is 68.55, and its symbol is Ba.

The oxide of Barium, BaO, called baryta or barytes, occurs abundantly in nature as carbonate and sulphate, forming the vein-stone in many lead mines. Pure baryta may be obtained by decomposing the crystallized nitrate at a red heat. The baryta is a greyish spongy mass, fusible at a high degree of heat. It forms a hydrate with water, with great elevation of temperature. The hydrate is a white soft powder, which has a great attraction for carbonic acid, the smallest trace of which renders its solution instantly turbid. Water, saturated with carbonic acid, dissolves $\frac{1}{820}$th part of baryta, forming what is called *baryta water*, which is a useful test for carbonic acid. Of all the bases, baryta has the strongest affinity for sulphuric acid, and is, therefore, used either in the state of baryta water or in that of one of its neutral salts, as the nitrate or muriate, to detect the presence and determine the quantity of that acid in any soluble compound. The peroxide of Barium, BaO_2, has not much interest in the useful arts, and indeed, the whole subject of this article belongs rather to scientific chemistry. The sulphate of baryta, or heavy spar, BaO, SO_3, is used as a pigment under the name of *permanent white,* but chiefly for the purpose of adulterating white lead; but as it does not form a body with linseed oil, its presence is injurious. Sulphate of baryta, on account of its cheapness and weight, is also employed in other cases of adulteration. The native sulphate was employed by Wedgwood in the manufacture of *jasper ware,* and for the production of opaque white patterns and figures upon a coloured ground. The specific gravity of the native sulphate is as much as 4.7, and that of baryta is about 4; hence its name, as being the *heaviest* (*βαρὺς*, heavy) of the substances usually called *earths.* Nearly all the barytic compounds are poisonous, but the sulphate of baryta is harmless; the best antidote, therefore, for the soluble barytic salts, is a solution of sulphate of soda.

BARK. The outer rind of plants, which in some cases yields an astringent principle called *tannin,* highly useful in medicine and the arts. The most important kinds of bark in a commercial point of view are undoubtedly Oak-bark and Peruvian bark. Oak-bark was for a long time the only substance used in England for tanning leather, and is still preferred before all other substances, although larch-bark has come into extensive use. Oak-bark is powerfully astringent, and would probably have remained the sufficient and only tanning material, had there not been a failure in the supply, which induced a search after other substances, and led to those experiments of the scientific of former days, and latterly of Sir Humphry Davy, by which several other barks yielding tanning materials were brought conspicuously into notice. Davy has ascertained the relative value of various substances in this respect, showing that 3½ lbs. of oak-bark are equal to 2¼ lbs. of galls, to 3 lbs. of sumach, to 7½ lbs. of the bark of the Leicester willow, to 11 lbs. of the bark of the Spanish chestnut, to 18 lbs of elm-bark, and to 21 lbs. of common willow-bark. The importation of common oak-bark has somewhat declined of late years, but is still very considerable from Belgium, Holland, Germany, Italy, Spain, Norway, and Australia. There is a kind of oak-bark imported from the United States, called Quercitron, the produce of the *Quercus tinctoria,* used in tanning, and also in giving a yellow dye to silk and wool. The colouring matter obtained from this bark is equal to that obtained from eight or ten times its weight of weld. The useful properties of quercitron were discovered and applied by Dr. Bancroft, who patented his invention in 1775. In the parliamentary returns of bark imported into the United Kingdom, there is no distinction made between the bark for tanning and dyeing purposes. The quantities imported in the years 1858, 1859, and 1860 were 349,838, 400,820, and 418,069 *cwts.*, respectively. The duty has been repealed. The proportion of tannin in oak-bark varies greatly with the season, and with the age of the tree. [See LEATHER.] Young trees barked in spring yield by far the largest amount. The operation of barking is thus performed:—When the tree is felled, and before it has been deprived of its larger branches, the whole are stripped of their bark by women called *barkers*, each furnished with a light short-handled mallet made of hard wood, the face of which is about 3 inches square, and the other end sharpened like a wedge. With the sharp part an incision is made along the side of the tree in a straight line, while cross-cuts are also made with a pointed instrument called the *barking bill*. A shovel-shaped instrument called a *peeling-iron* is then forced between the bark and the wood, separating the former without difficulty in entire pieces. These are carefully dried for two or three weeks, and then piled in stacks and sold to the tanner.

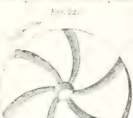
Next in importance to oak-bark, is the Peruvian or Jesuits' Bark, well-known as a valuable medicine. Of this there are three principal species, known in commerce as *pale*, *red*, and *yellow* bark. The first is the produce of *Cinchona lancifolia*, and is the crown cinchona of Peru. It is received in chests covered with skins, each containing about 200 lbs., consisting of pieces 8 or 10 inches long, and singly or doubly quilled, or rolled inwards. It is of a pale fawn or cinnamon colour, and has very little odour while dry, but the decoction is agreeably aromatic. The taste is a fine bitter, but austere. This species is becoming more and more scarce. The second, or red bark, is obtained from *Cinchona oblongifolia*, growing on the Andes, and is received in chests weighing from 100 to 150 lbs. each. This kind is mostly in flat pieces of various sizes, with occasionally some that are quilled; the internal part being woody, and of a rust red colour. Red bark has a weak peculiar odour, and a less bitter, but more nauseous taste than the other barks. The third, or yellow bark, is the produce of *Cinchona cordifolia*, growing in Quito and Santa Fé. The chests contain from 90 to 100 lbs. each, in pieces from 8 to 10 inches long, some quilled, but the greater part flat. The interior is yellow approaching orange-colour. It has nearly the same odour in decoction as the pale, and has a more bitter and less austere taste. If the colour of the specimen be variable, it is not of the first quality, and if it be dark between red and yellow, it should be rejected. The medical uses of Peruvian bark are said to have been first discovered by the Jesuits. This important substance was brought to Europe in 1632, but was not much used till the latter end of the seventeenth century. Humboldt estimates the quantity now annually exported from America at from 12,000 to 14,000 quintals. In the pale Peruvian bark there exists a principle called *cinchonia*, and in the yellow bark an analogous but distinct principle called *quinia*, both of which are obtainable by a somewhat expensive process, and are abundantly prepared for medical use. The valuable properties of the bark are thus available in a concentrated form. Sulphate of Quinia or Quinine is now an object of especial attention, and is manufactured both in this country and on the continent to a very great extent. The annual export from Paris alone, is estimated at 120,000 ounces.

BARLEY. An important grain for malting purposes, but a bad bread corn: "*Grossier comme pain d'orge*" is a French proverb. Barley is extensively cultivated in most temperate climates, and is even raised within the tropics, but not at a lower elevation than about four thousand feet. The principal sowing season in our own country is in March or April, according to the situation. This crop generally follows turnips, potatoes, or pulse, and is important in the rotation adapted to light soils. It seldom follows wheat and oats, unless after three ploughings, and then only under certain circumstances. The produce varies, according to season, situation, and preparation of the soil, from 20 to 60 or 70 bushels per acre. From 30 to 40 bushels is a usual crop. The nutritive matter obtained from barley is reckoned at 65 per cent.; that of wheat at 78 per cent. A bushel of barley, weighing 50lbs., will consequently contain about 32lbs. of nutriment. The barley crop is of great importance in England, and occupies the ground about four months. The best barley counties are the middle line of counties from east to west. In Egypt and similar genial climates two crops of barley may be raised in the same year; one in spring, from seed sown the previous autumn, and one in autumn, from a spring sowing. By the hail which desolated Egypt during the sojourn of the children of Israel "the flax and the barley were smitten: for the barley was in the ear, and the flax was bolled. But the wheat and the rye were not smitten: for they were not come up."—Exod. ix. 31. This event is computed to have happened in the month of March, at which time the first crop of barley was nearly ripe, and the flax ready to pull. But the wheat and rye sown in spring were not sufficiently forward to receive injury.

Pot barley is barley deprived of its outer skin. Pearl barley, also called Scotch or French barley, is barley deprived not only of the skin, but of a portion of the grain, leaving merely a small round kernel. Both preparations are made by means of the same kind of mill, but the pearl barley receives a greater degree of the grinding process. The grain is kiln dried before it is ground. The simplest form of mill, and that which is now in use on the Continent, resembles a common flour-mill, with two mill-stones, each about three feet in diameter, one fixed, the other revolving over it. The upper stone has six grooves cut in the lower surface, from the centre to the circumference (Fig. 92), and a perforation in the centre. It revolves on a vertical axis of iron, the lower point of which moves in a metal cup fixed on an elastic horizontal beam

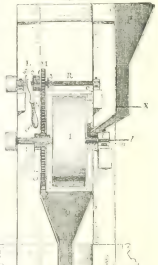
The upper stone moves parallel to the lower, and so close to it as to rub without crushing the grain which passes between them. The mill is fed by a hopper, through the central opening, as in the common corn-mill. The stones work in a cylindrical box or case, the top of which is of wood, with a circular opening corresponding to that of the stones. The circumference of the box is of thin iron plates, punched with numerous holes, so as to resemble a nutmeg-grater, the rough surface of which is within, and assists the operation of removing the skin from the barley. Before being placed in the hopper, the barley is slightly moistened with water, and turned two or three times, in order to loosen the skin; it is then gradually supplied by the hopper to the action of the stones: it enters the grooves in the upper stone, and is whirled round at the rate of two or three hundred revolutions per minute, thus breaking the skin, and strongly rubbing, but not crushing, the grain against the under stone. It is then driven off with considerable force against the grating surface of the cylinder, which, together with the current of air produced in the process, completely removes any remaining skin from the grain. From the cylinder it is let out through a square opening, and falls on a sieve, where the naked barley is separated from the bran. The greater part of the fine particles of barley escape through the holes in the cylinder during the process; therefore, to avoid waste, a cloth is fastened round the cylinder, and guides the meal into a bin below. This mill answers very well for pearl barley, but for simply removing the skin, or making pot barley, it has these disadvantages,—that it requires great nicety in the adjustment of the stones, and that, with every precaution, the barley is ground unequally, the larger grains losing more of their substance than is desirable.

Fig. 92.



The supply of pearl barley to this country, and indeed to the rest of Europe, was formerly a Dutch import; hence it was called Dutch pearl barley; but at present the manufacture is largely carried on within our own dominions, and we receive the larger portion of our pot and pearl barley from Scotland. The mill commonly used in that country consists of one ordinary grindstone, such as cutlers use, revolving on a horizontal axis, passing through the centre of an outer case, shown in section *a b c d*, and entire in Fig. 94, which moves at a slower rate, by the means shown in Fig. 94. The outer case is moved by a pinion M fixed to the spindle R, at the opposite end of which is a drum, connected by an endless band with the moving power. The stone I is also moved by a similar contrivance. The pinion M is fixed to the spindle R by means of a brass bush fitted into the centre of the pinion, and then bored exactly to fit a conical place in the spindle R. Below the base of the cone is a brass ring 3, to keep the pinion M firm upon the cone by means of four screw-bolts which bring the pinion firmer to the base of the cone. On the other side the pinion are two projections or snags, 1, which take into similar projections on the end of the catch 2 5. This catch slides along the spindle R by moving the lever N, but goes round with the spindle by means of two tongues fixed on the opposite sides of the spindle, one of which is partly visible at 4. Two grooves are cut in the inside of the catch, to admit the tongues, in order to carry the catch round with the spindle. The wheel N O, having 102 teeth, and a diameter of 4 feet 1⅛ inches to the pitch stroke, is screwed to the sides of the drum that incloses the stone. This drum, which is shown in section *a b c d*, is lined with milled iron, pierced with small holes, in order to permit the escape of the dust, and to act as a grater to the barley.

Fig. 93



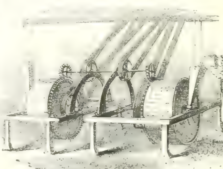


Fig. 94.

When the drum is turned round by the wheels already described, it is supported and kept clear of the stone by the collars *h i*. The collar *h* is larger than *i*, in order to give room to the spout P, to fill the drum with barley. This is effected by a thin plate of iron *k*, about an inch larger in diameter than the inside of the collar, which is kept close to the side of the collar next the stone by the staple *l* on each side of the stone spindle. The other end of it is kept fast by the cover of the pillow-block *m*. In the plate *k* a hole is cut for the end of the spout. When the barley is made, the drum is stopped by pulling the lever N towards *f*. A small sluice which is upon the side of the drum, Fig 94, is then opened, and the barley is allowed to run off into the trough Q. When the drum is thus emptied, the sluice is shut, and the lever N is moved back, by which means the wheel M engages with the spindle R by the catch 2 5, and the sluice x being opened, the drum is filled with fresh barley. When this machine is set in motion, the barley is so thoroughly tossed and beaten between the stone and the case, owing to the double motion, that it is entirely deprived of its skin, and, if the process be continued, it also loses a further portion of its substance, and becomes pearl barley. By means of this machine three bushels of barley may be converted into pot barley in an hour, and into pearl barley in two hours.

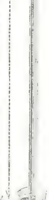
BARM. Another name for YEAST, probably from *beren*, to raise. See BEER.

BAROMETER. The application of this word, from *βάρος*, weight, and *μέτρον*, a measure, is not very appropriate, the common balance being rather a measurer of weight than this instrument, which merely indicates or measures the variations in the pressure of the atmosphere. The barometer is one of the most valuable instruments ever contrived for assisting the philosopher in searching out the laws of the wonderful ocean of air in which we live, and its invention belongs to a highly interesting period in the history of science. Some time previous to the year 1643, a pump was sunk at Florence for the purpose of raising water from an unusually great depth, when, upon working it, it was found that the water would rise no higher than about 32 feet. Galileo was consulted, but he did not explain the phenomenon satisfactorily. After his death, his pupil, Torricelli, who had long meditated on the subject, devised the following experiment, in the year above mentioned. He took a glass tube, about 4 feet in length, closed at one end and open at the other, and, having filled it with mercury, closed the open end with his finger, inverted it, and placed the open end below the surface of mercury contained in a basin. Holding the tube in a vertical position, he withdrew his finger, and observed that the mercury sank in the tube a certain distance, and, after a few oscillations, settled at the height of about $27\frac{1}{2}$ inches above the surface of the mercury in the basin.[1] On comparing the height of the column of mercury with the height of the column of water raised by the pump, he found these heights to be in an inverse ratio of the specific gravities of the water and mercury. Observing also that the columns of water and mercury had no communication with the atmosphere at their upper extremities, but that they did communicate therewith at their lower extremities, he concluded that the two columns were suspended by the same cause, namely, the weight or pressure of the atmosphere.

In 1646, Pascal at Rouen verified Torricelli's experiment, and also varied it by employing liquids of different specific gravities; he found that the lighter the liquid, the greater the height of the column in the tube. But, as the effect of an invisible fluid like the air in supporting a column of so ponderous a fluid as mercury was still doubted, Pascal suggested a complete *experimentum crucis* by observing the height of the column of mercury supported at the bottom, and at the top, of a considerable elevation. Two tubes filled with mercury were conveyed to the mountain Puy de Dome, near Clermont, in Auvergne. At the base they both stood at 28 inches; one was left there, and the other taken to the summit. As the observers ascended, the mercury in the tube sank gradually to 24.7 inches, and as they descended, the mercury as gradually rose again to its former elevation. This result was exactly what Pascal had anticipated; for, if the cause which sustained the column in the tube were the weight of the atmosphere acting upon the external surface of the mercury in the basin, then it was to be expected that on taking the tube to the top of a mountain, a gradually diminishing quantity of atmosphere would be above it, and the column of mercury sustained by the weight of this incumbent atmosphere must undergo a corresponding diminution in height. The experiment was repeated by Pascal himself, with similar success, by taking one of the tubes to the top of a high tower in Paris. It was further observed that by keeping the tube for a length of time in a fixed position, the height of the column was found to vary from day to day within certain small limits: an effect which could only be ascribed to fluctuations in the weight of the atmosphere itself.

The simple apparatus devised by Torricelli, consisting of a tube of mercury dipping into a cistern of the same metal, is in fact the barometer. Although this instrument has been distorted into endless varieties of shape, and with numerous additions, yet they have been abandoned one after the other, and the simple form in which Torricelli first observed the effect of atmospheric pressure in sustaining a column of mercury, has long been admitted to be the best form of apparatus for noting the daily and hourly fluctuations in that pressure. There are, however, certain precautions necessary to be attended to, both in the filling of the tube and in making observations.

Fig. 95.



The essential parts of a good barometer are a well-formed glass tube, Fig. 95, 33 or 34 inches long, of equal bore, containing pure mercury; a cistern of mercury, for receiving the open end of the tube; and an accurately-adjusted scale, for ascertaining the exact height of the column.

The mercury must be purified from all baser metals, such as tin, lead, zinc, and bismuth, all of which it dissolves with facility, and which [illegible]; for, as the specific gravity of each of these metals is much less than that of mercury, their presence would cause the height of the barometer to be greater than that of an instrument containing pure metal only. Mercury appears to be incapable of retaining either air or moisture, and the air-bubbles which rise from it when heated or relieved of atmospheric pressure are merely retained between the mercury and the glass vessel in consequence of the attraction existing between glass and air.

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[1] The vacant space thus formed between the top of the mercury and the top of the tube is called the Torricellian vacuum.

On pouring mercury into the barometer tube and inverting it, as in the Torricellian experiment, the film of air confined between the mercury and the inner surface of the tube, being relieved from pressure, will escape into the Torricellian vacuum, where it will by its elasticity oppose the pressure of the external air, and constantly maintain the mercurial column at a lower level than if the vacuum were perfect; so that the observed height of the column would indicate only the excess of the pressure above that within the tube. In order to get rid of this air, and any moisture within the tube, the mercury is introduced in small portions at a time, and boiled over a charcoal fire between each introduction, holding that part of the tube over the fire which contains the last portion of mercury introduced. The filling of a barometer tube requires many precautions, which are usually noticed in works devoted to the subject.[1] When the tube is properly filled, it is inverted into a cistern of pure mercury, and when the column sinks to the proper level, its length above the surface of the mercury in the cistern exactly counterbalances the atmospheric pressure, unless, indeed, we take into account the minute quantity of vapour of mercury which, above the temperature of 60°, rises into the Torricellian vacuum; but this is so slight a cause of deterioration that it may be neglected.

The precautions taken to ensure contact between the mercury and the interior of the tube cannot of course be used for the exterior, where the tube is surrounded by the mercury in the cistern. A film of air is always retained at this part of the tube, and also at its under edges, which film creeps by small portions at a time into the interior, and rises up in minute bubbles into the vacuum, the film being constantly renewed by the descent of more air between the outside of the tube and the mercury in the cistern. In this way the most carefully constructed barometers deteriorate in the course of years, as was shown by Professor Daniell, on a comparison of the registers of the celebrated Meteorological Society of the Palatinate.

In the register kept at Mannheim for twelve years, from 1781 to 1792, inclusive, the mean height of the barometer for the second six years is .062 inch lower than that of the first six years.

In the register kept at Padua during the same period, the mean of the last six years is .044 inch lower than that of the first six.

In the register kept at Rome, the average of the last six years is lower than that of the first by .114 inch.

At Buda the difference is .035 inch; at Brussels .044 inch; at Munich .026 inch; from the summit of Peisenberg, a mountain in Bavaria, .026 inch; and from the summit of Mount St. Gothard the depression is also .026 inch.[2]

This irregular and uncertain deterioration of barometers cannot be too greatly deplored, because it vitiates the observations of all those earnest and competent observers who during many years have devoted daily portions of their valuable time to a record of the oscillations of the barometer at various stations. Indeed, until the defect complained of was remedied by Professor Daniell, the great mass of barometrical observations can scarcely be said to be of any scientific value. The remedy consists in welding a ring of platinum to the open end of the barometer tube, so as to bring it in contact with the mercury: by this simple means the ingress of air into the tube has been effectually prevented.

The same excellent man and distinguished philosopher also invented a new mode of filling barometer tubes, by screwing the tube into the under surface of the table of an air-pump, and making such arrangements as enabled him to fill the tube and also to boil the mercury in vacuo. For the details of this contrivance we must refer to the original essay; but it may be noticed, as a striking proof of the absence of air and the perfect contact of the mercury with the glass, that, although the bore of the tube was more than half an inch, yet, on inverting it, the mercury did not fall at once to its usual height, but remained suspended to the top of the tube, until detached therefrom by a few concussions.

The excellence of a barometer may be tested by the brightness of the mercurial column, and the absence of any flaw, speck, or dulness of surface; secondly, by what is called the *barometric light*, or flashes of electric light in the Torricellian vacuum, produced by the friction of the mercury against the glass, when the column is made to oscillate through an inch or two in the dark; thirdly, by a clicking sound produced by the mercury striking the top of the tube when the column is made to oscillate. If air be present it will form a cushion at the top, and prevent or greatly modify this click.

The sectional area of the tube is of no consequence to the height of the column of mercury supported. If the sectional area be equal to 1 square inch, the column of mercury 30 inches high will be counterbalanced by a column of atmospheric air 1 inch square, and extending from the surface of the mercury in the cup *b*, Fig. 95, to the top of the atmosphere; and as we know the pressure of the air to be about 15 lbs. on the square inch, so the column of mercury 1 inch square in the barometer tube weighs about 15 lbs. If instead of mercury we take 15 lbs. of water, and form it into a column 1 inch square, we get in such case a height of about 33¾ feet. If the sectional area of the tube of the mercurial barometer be only half an inch, the column of mercury will still retain the same height, for it is counterbalanced by the same height of atmosphere, only the column of atmosphere has in this case a base of only half a square inch instead of an inch. So long therefore as the atmosphere presses with the same intensity upon the surface of the mercury in the cup, the column suspended in the tube will be of the same height whatever be its internal diameter.

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[1] The construction of the barometer and other meteorological instruments [illegible] in the [illegible] "Treatise on Pneumatics," [illegible].

[2] Professor Daniell remarks — "There is a defect which may [illegible] be observed in old looking-glasses, which may perhaps be [illegible] to the same cause as the deterioration of barometers. I allude to a dulness which takes place in [illegible] their [illegible] and which generally [illegible] from the centre. I have frequently remarked this in the very old [illegible] in the palaces [illegible] on the Continent. I [illegible] from the slow insinuation of air by the [illegible] crack in the metal at the back of the glass." A damp [illegible] would also produce a similar effect upon looking-glasses, the moisture probably favouring the entrance of the air. See "Elements of Meteorology," vol. [illegible], London, 1845. The two [illegible] on the "Construction and Deterioration of Barometers" are [illegible] specimens of patient research, which [illegible] interested in the subject.

It has been already stated that the height of the mercurial column *a b*, Fig. 95, must be measured from the surface of the mercury in the cistern. Now it will be obvious that the level of the surface must always change with the oscillations of the column. When the atmospheric pressure increases, and the mercury in the tube rises, a portion of the metal is drawn out of the cistern into the tube, and the level of the mercury in the cistern is depressed. So on the contrary, when the atmospheric pressure diminishes, a quantity of mercury is forced out of the tube into the cistern, and the level of the metal in the latter rises. If therefore the instrument be furnished with a fixed scale at the top of the column, graduated when the distance between the top of the column and the level of the mercury in the cistern is exactly 30 inches, it will be evident that when the top of the column sinks to 29 inches on the scale, the distance between the two extreme points will not be 29 inches, but somewhat less, depending on the capacity of the cistern. So also, if the column rise to 31 inches, the distance will be rather more than this, on account of the additional quantity of mercury drawn into the tube. If the cistern be a section of a cylinder with a flat bottom, bearing a certain known proportion to the bore of the tube, such as 1 : 100, and the mercury rise 1 inch above the neutral point, then as much mercury will be withdrawn from the cistern as fills 1 inch of the tube; but as the base of the cistern is 100 times greater than the bore of the tube, it is obvious that this inch of mercury in the tube would cause a fall of only $\frac{1}{100}$th of an inch in the level of the mercury in the cistern; or in other words, the fall of $\frac{1}{100}$th inch in the mercury in the cistern is accompanied by a corresponding rise of $\frac{99}{100}$ths in the tube. A similar effect is produced by any other change in the height of the column, so that if the inches on the graduated scale be made each $\frac{1}{100}$th part less than an inch, the instrument will afford tolerably correct results. In some instruments, however, the scale accurately divided into inches and parts of inches is made movable, and terminates in an ivory point which is brought down to the surface of the mercury. When this point and its reflection appear to be in contact, the height indicated by the scale is correct. In other forms of the barometer, the mercury in the cistern is always maintained at the same level, for which purpose the cistern is formed partly of leather, so that by means of a screw at the bottom the surface of the mercury may always be adjusted to the neutral point before taking an observation. The cistern is also sometimes provided with a gauge or float, which indicates when the mercury in the cistern is too high or too low. By turning the screw one way or the other, the mercury in the cistern is adjusted to the proper level. When there is no gauge, the relative capacities of the cistern and tube are ascertained and marked on the instrument together with the neutral point. In an example given by Mr. Belville,[1] the capacity for every inch of elevation of the mercury in the tube is supposed to be equal to $\frac{1}{40}$th, which reduced to a decimal = 0.025 inch for 1 inch; 0.013 inch for ½ inch; 0.007 inch for ¼ inch.

		Inches.
Then if the observed height	=	30.400
And the neutral point be	=	30.000
The difference above the neutral point will be		.400
Then add for capacity	+	.010
The correct height will be		30.410

In this case the observed height is above the neutral point. In the following example it is below it.

		Inches.
Observed height	=	29.500
Neutral point	=	30.000
Difference below neutral point		.500
Subtract for capacity	−	.013
Correct height		29.487

As the range of the barometer in this country is limited to about 3½ inches, it is not necessary to commence the scale from the neutral point. The divisions usually begin at the 27th inch, and are continued to the 31st. But in instruments intended to measure the height of mountains, or for accompanying balloons, the scale begins at the 12th or the 15th inch. Each inch is divided into 10 parts, and these are subdivided into hundredths by means of a little sliding scale called a vernier or nonius[2] attached to the side of the large scale as in Fig. 96. It measures exactly one inch and one-tenth in length, and is divided into 10 equal parts numbered from the top downwards, while the divisions of the inches of the scale are numbered from the bottom upwards. Now as 10 divisions on the vernier are equal to 11 on the scale, and as those 10 are all equal to each other, it follows that each division of the former must be equal to $1\frac{1}{10}$ division of the latter, or to $\frac{11}{100}$th inch. If therefore any division on the vernier

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(1) A Manual of the Barometer. By J. H. Belville, of the Royal Observatory, Greenwich. London, 1849. This cheap but excellent little work ought to be in the hands of every one who uses a barometer.

(2) So called from Peter Vernier, a gentleman of Franche-Comté, who described it in a tract printed at Brussels in 1631. The word nonius is derived from Peter Nunnez or Nonius, whose name has been Latinised, a Portuguese Mathematician born at [illegible]

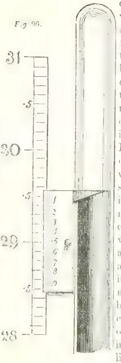


Fig. 96.

coincide, or is in a line with a division on the scale, the two lines immediately above or below those which coincide will be separated by a distance exactly equal to $\frac{1}{100}$th inch; the pair, two divisions removed from the first, has a deviation of $\frac{2}{100}$ths of an inch, and so on. Thus in Fig. 96, the line marked 6 on the vernier coincides with the line 28.9 on the scale, but the two lines immediately above them, marked 5 and 29, do not exactly coincide; and this want of coincidence must amount to $\frac{1}{10}$th of $\frac{1}{10}$th of an inch, or $\frac{1}{100}$th of an inch. In the next two lines, marked 4 and 29.1, it will be seen that they fail to coincide by $\frac{1}{10}$th of $\frac{2}{10}$ths of an inch, or $\frac{2}{100}$ths of an inch. In like manner the lines marked 3 and 29.2, 2 and 29.3, 1 and 29.4, and 0 and 29.5, deviate from each other respectively by $\frac{3}{100}$, $\frac{4}{100}$, $\frac{5}{100}$, and $\frac{6}{100}$ths of an inch. The same reasoning will also apply to the lines situated below the coincident lines marked 6 and 28.9. Thus 7 and 28.8 immediately below them fail to coincide by $\frac{1}{100}$th of an inch, and so on with respect to the others. The point to be attended to is that a division on the vernier is $\frac{1}{100}$th of an inch larger than a division on the scale.

In applying the vernier to measure off small fractions of an inch in the height of the barometer, we first notice the height of the column by the fixed scale, which in Fig. 96 is more than 29.5 inches, but less than 29.6. In order to measure the hundredths of an inch, we place the zero or top of the vernier scale exactly level with the top of the mercury; we next observe that of all the lines on the vernier only one can coincide with a line on the scale. In the figure the line marked 6 on the vernier coincides with a line on the scale; and as from the top of the mercury to these coincident lines there are six pairs which do not coincide, and as each pair deviates by $\frac{1}{100}$th of an inch more than the pair below it, the uppermost pair must evidently differ by $\frac{6}{100}$ths of an inch. We thus get the height of the mercury in our figure, which is 29$\frac{1}{2}$ inches and $\frac{6}{100}$ths of an inch, or, expressed decimally, 29.56.

The words "Change," "Fair," and "Rain," engraved on the plate of the barometer, are calculated to mislead the observer; for, as Mr. Belville observes, "from the observations of two centuries we find that heavy rains and of long continuance take place with the mercury at 29.5 inches, or 'Change;' that rain frequently falls when it stands as high as 30 inches, or 'Fair;' and, more particularly in winter, a fine bright day will succeed a stormy night, the mercury ranging as low as 29 inches, or opposite to 'Rain.' It is not so much the *absolute* height as the actual rising and falling of the mercury which determines the kind of weather likely to follow." Instrument-makers still continue to engrave these words on the scale, apparently for no other reason than old-established usage; their customers would probably think the instrument imperfect without them, just as the readers of Moore's Almanack insist upon having the supposed influence of the planets upon the different members of the body entered for every day in the year. Indeed, the defects of the common barometer, as it leaves the hand of the instrument-maker, are so serious as to render this instrument almost worthless to science. "In the shops of the best manufacturers and opticians," says Professor Daniell, "I have observed that no two barometers agree; and the difference between the extremes will often amount to a quarter of an inch; and this with all the deceptive appearance of accuracy which a nonius, to read off to the five-hundredth part of an inch, can give. The common instruments are mere playthings, and are by no means applicable to observations in the present state of natural philosophy. The height of the mercury is never actually measured in them, but they are graduated from one to another, and their errors are thus unavoidably perpetuated. Few of them have any adjustment for the change of level in the mercury of the cistern, and in still fewer is the adjustment perfect. No neutral point is marked upon them, nor is the diameter of the bore of the tube ascertained; and in some the capacity of the cistern is perpetually changing, from the stretching of a leathern bag, or from its hygrometric properties. Nor would I quarrel with the manufacture of such playthings: they are calculated to afford much amusement and instruction; but all I contend for is, that a person who is disposed to devote his time, his fortune, and oftentimes his health, to the enlargement of the bounds of science, should not be liable to the disappointment of finding that he has wasted all from the imperfection of those instruments upon the goodness of which he conceived he had good grounds to rely. The questions now of interest in the science of meteorology require the measurement of the five-hundredth part of an inch in the mercurial column; and, notwithstanding the number of meteorological journals, which monthly and weekly contribute their expletive powers to the numerous magazines, journals, and gazettes, there are few places indeed of which it can be said that the mean height of the barometer for the year has been ascertained to the tenth part of an inch."

The barometer ought to be fixed in a truly vertical position, and, if possible, with a northern aspect, in order that it may be subject to as few changes of temperature as possible. It is usual, for the sake of comparison, to reduce the observations to 32°, for which purpose tables for correction for temperature are given in scientific works devoted to the subject of the barometer. "The height of the cistern of the barometer above the level of the sea, and, if possible, the difference of the height of the mercury with some standard, should be ascertained, in order that the observations made with it should be comparative with others made in different parts of the country. Before taking an observation, the instrument should be gently tapped, to prevent any adhesion of the mercury to the tube; the gauge should be adjusted to the surface-line of the cistern, and the index of the vernier brought level with the top of the mercury." The best times of the day for observing the barometer are at 9 A.M. and 9 P.M., when it stands higher, and at 3 A.M. and 3 P.M., when it stands lower, on an average, than any other times during the twenty-four hours; as may be proved by examining a barometric register kept for a long period, and taking the average of each set of observations made at the same hour. In this climate, and in summer, the mean of a few weeks is sufficient to elicit this fact. As 3 A.M. is an inconvenient time for observations, a person with time at his disposal should select the other three hours for making his entries. If he can make only two observations, the proper periods are the convenient hours of 9 A.M. and 9 P.M. If he can make only one observation, then *noon* is the time. Professor Daniell remarks that those who merely consult the barometer as a weather-glass would find it an advantage to attend to the three above-mentioned periods, for he has noticed that by much the safest prognostications from this instrument may be formed from observing them when the mercury is inclined to move contrary to its periodical course. If the column rise between 9 A.M. and 3 P.M., it indicates fine weather; if it fall from 3 to 9, rain may be expected.

In the application of rules for prognosticating the weather, by observations made on the barometer, the most important fact to be remembered is, that the state of the weather to be expected is not so much connected with the absolute height of the column as with its motion, whether rising or falling. A fall in the mercury generally indicates approaching rain, high winds, or a thunder-storm; but snow is more frequently preceded by a rise than by a fall. With this exception, a rising state of the barometer commonly indicates the approach of fine weather. The lowest depressions occur with the wind at S. and S.E., when much rain falls, and frequently short and severe gales blow from these points. A N.E. wind is more conducive to a high state of the barometer than any other. When the mercury rises or falls steadily for two or three days together, it is generally found that rather a long continuance of settled weather will follow: rainy in the latter case, and fine and dry in the former. By the same rule, frequent fluctuations in the height of the column are found to coincide with unsettled weather.

In a tube of small bore, when the mercury is rising its surface is convex; when it is falling it is concave, as if the centre of the fluid column always preceded the sides in all its motions. In such a tube, in nice observations, a correction has to be made for capillarity. Corrections for temperature, which acts unequally upon the mercury, the glass of the tube, and the metal of the scale, are also made in accurate observations, and tables are provided for all these purposes.

The causes of the oscillations of the barometer are too intricate to be discussed within the limits of a short article, but the reader will find them stated at some length in the treatise on Pneumatics, in Weale's Rudimentary Series. When the barometer is used alone, it has a far more direct application to the theory of the winds than to that of rain, and with this view Mr. Belville has constructed the best set of rules we have ever seen, connecting the phenomena of the barometer with the direction of the wind, and also with the appearance of the clouds, according to Howard's nomenclature. These rules occupy 11 pages of Mr. Belville's little manual, to which we must refer. This work also contains a table showing the mean height of the barometer at noon for Greenwich, for every day in the year, deduced from 30 consecutive years' observations, viz. from 1815 to 1844, and reduced to 32° Fahr. The following are the monthly means from this table.—

January	29.909	second maximum
February	29.859	
March	29.857	second minimum
April	29.856	
May	29.884	
June	29.910	maximum
July	29.894	
August	29.890	
September	29.872	
October	29.851	
November	29.801	minimum
December	29.881	

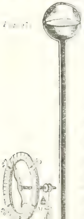
The mean annual pressure for noon at Greenwich is 29.872 inches.

It appears from Mr. Belville's table, that "at certain seasons of the year, great periodic maxima and minima take place. The greatest daily mean pressure for the year occurs about the 9th January, and the minimum daily mean depression towards the end of November. It is a remarkable coincidence, that the lowest daily mean temperature for 30 years, occurs on the 8th and 9th of January, and the daily mean temperature for November rises suddenly 4° in the last few days in November."

From a table of the greatest and least observed heights of the barometer at Greenwich, between 1811 and 1848, it appears that the maximum elevation for the 38 years, occurred in 1825, when the mercury stood at 30.89 inches; in 1821 it reached 30.82 inches; in 1835, 30.84 inches, and in February 1849, 30.86 inches. In the extreme depressions those of 1821 and 1843 differ only by 21 hundredths; the first occurred on the 25th December, when a Troughton's mountain barometer sank as low as 27.89 inches. "A heavy rain of some hours' duration with the wind at south-east, had preceded the minimum pressure; a gale from the north-west followed, in which the mercury rose a few tenths. The depression of 1814, 28.21 inches, happened at the close of the great frost, and was likewise preceded by a stormy wind from SS.E. and much rain."

The common wheel-barometer or weather-glass, is a contrivance for increasing the length of the scale. It has no scientific value, but as it is in very common use as a piece of furniture, some notice may be expected of it in a popular work. In this instrument the tube instead of terminating at the bottom in a cistern, is recurved so as to form an inverted syphon, as in Fig. 97. As a rise in the mercury in the longer or closed limb is equivalent to a fall in the shorter limb, and vice versâ, a float is placed on the surface of the mercury in the shorter limb, and is connected with a string passing over a pulley, and very nearly balanced by another weight on the other side. An index hand attached to the pulley moves over the surface of a dial plate, graduated so as to indicate the oscillations of the column. With an increase of pressure the mercury in the longer tube rises, and that in the short tube is depressed, together with the float, and this gives a small motion of revolution to the pulley and also to the index hand. A fall in the longer column causes the mercury with its float in the short limb to rise, and consequently moves the index-hand in the contrary direction. This barometer is very inferior to the vertical or cistern barometer, because a change of pressure such as would make a difference of nearly an inch in the upper level of the latter, would show but half an inch in each level of the syphon; for, although the surfaces of the mercury in the two limbs would be an inch further apart, that inch would be compounded of a rise of half an inch at one surface and a corresponding fall at the other. Our unit of measure, therefore, becomes only half as great, and necessarily diminishes in utility. In Fig. 97, however, the upper end of the tube is expanded into a bulb, in order that, by enlarging the upper surface of the mercury, the difference of level may be made to depend almost entirely on the lower surface, giving the same advantage as in a common barometer, with a cistern of the same horizontal area as the bulb.

Fig. 97.



For the measurement of heights, and as an instrument for accompanying the scientific traveller, barometers have been made portable. Fig. 98 represents Troughton's portable barometer, closed so as to protect the instrument and render it portable, and Fig. 99 shows it mounted on a tripod ready for use. The staff-head is constructed in a peculiar manner for the purpose of suspending the barometer. It consists of a circle, Fig. 100, about $\frac{3}{4}$ of an inch broad, joined in three pieces; the three joint-pins extend inwards so as to pass through a circular rim which they hold fast; within this rim is hung a similar one by two pivots; and within the latter, at right angles to the pivots, are fastened two angles, in which the barometer hangs by its gudgeons. By this ingenious arrangement, the legs of the tripod can be extended, and the instrument is supported by, and can be turned about on, a universal joint, on which it adjusts itself in a plane perpendicular to the horizon. The cistern, Fig. 101, is a glass cylinder about $2\frac{1}{2}$ inches in diameter and the same in length. An external brass tubing, terminating in an interior screw a little above and below the glass, admits external screw pieces whose ends, covered with leather, being pressed firmly against the ends of the glass, prevent the escape of the fluid. Near the upper end of the brass cover of the cistern are two horizontal slits opposite to each other, one before and the other behind. At the bottom is a screw, by turning which the leather bag is compressed and the mercury forced to the top of the tube, and thus filling every part, the instrument is rendered portable. This screw also furnishes the means of adjusting the surface of the mercury in the glass cistern, so as just to shut out the light from passing between it and the upper edges of the slits in the brass cover. This is the mode of adjusting to zero, the upper edges of the slits representing the commencement of the scale of inches. The frame is also of brass tube about $1\frac{1}{10}$th inch in diameter. The first 10 inches of the lower end is occupied by a thermometer, the bulb of which is bent inwards and concealed within the frame. At about three inches higher, it is attached to the stand by the ring, Fig. 100, in which the frames turn smoothly for the purpose of placing the instrument in the best light for reading off. The divided scale commences at 15 inches above the neutral point, and is continued as high as 33 inches, and by the help of a vernier is subdivided into the $\frac{1}{1000}$th of an inch. A longitudinal slit from end to end of the divided part, exposes the glass tube and mercury. The

Fig. 98.

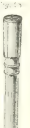


Fig. 99.

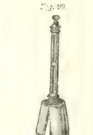


Fig. 100.

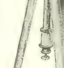
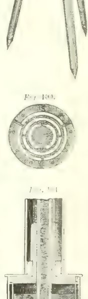


Fig. 101.

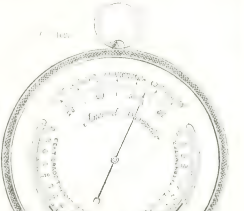


whole of this part is formed of two tubes of brass; in the inside of the interior one, a cylindrical piece slides, and on this is divided the vernier scale, the index to which is the lower end of the piece. In taking the height of the mercury, this piece is brought down by means of the screw at the top, so as just to exclude the light from passing between itself and the spherical surface of the top of the column of the mercury. The screw at the top acts upon the interior tube, within which the vernier piece is sustained by friction, and is first set by hand and then adjusted by the screw.

Soon after the invention of the barometer, attempts were made to construct a water-barometer, on the supposition that the greater range of its oscillations would measure more minute changes of pressure. The most perfect instrument of this kind was constructed by Professor Daniell, in the hall of the Royal Society at Somerset House. It consists of one entire tube of glass 40 feet long. Its diameter is about an inch, and the average height of the fluid column 400 inches. When originally erected in the year 1832, the water in the cistern was covered with a layer of castor oil; but as this did not prevent the admission of the outer air, it was found necessary to refill the tube. This was done in January 1845, and a solution of caoutchouc in naphtha was substituted for the castor oil. In windy weather, this barometer appears to be constantly fluctuating, indicating numerous changes of pressure, which have no sensible effect on the most delicate mercurial barometer; the column appears to be in a state of perpetual motion, similar to the slow act of respiration. But the most important result is, that this instrument precedes by one hour the mercurial barometer of half an inch bore, as this does the mountain barometer of 0.15 inch bore, by the same interval in their horary oscillations; showing that while scientific men are disputing about the hours of the maxima and the minima, much depends upon the construction of the instrument observed.

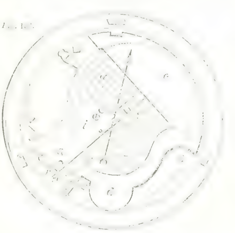
The *Aneroid* barometer, by M. Vidi, is so named from *α* "without," and *νηρος* "fluid;" its indications being obtained without the use of mercury or any other fluid. Its action depends on atmospheric pressure on a metallic box, from which the air has been exhausted, and then hermetically sealed. An index traversing a dial records the changes in the weight or pressure of the air on a given surface. It is $4\frac{3}{4}$ inches in diameter across the face, and $1\frac{3}{4}$ inch in thickness. It is graduated to correspond with the common barometer, and two small thermometers are fixed on the face of the dial. Fig. 102 represents the external appearance of the instrument, and Fig. 103 the internal construction as seen when the face is removed, but with the hand still attached. *a* is a flat circular box about $\frac{1}{4}$ inch in depth, made of some white metal, the upper and under surfaces of which are corrugated in concentric circles to give it greater elasticity. This box being exhausted of air through the short tube *b*, and then made air-tight by soldering, forms a spring which is affected by every variation of pressure in the external atmosphere. It is attached to the bottom of the

Fig. 102.



metallic case, which encloses the mechanism of the instrument. At the centre of the upper surface of the elastic box is a solid projection *x*, about half an inch high, to the top of which, the principal lever

Fig. 103.



c,d,e, is attached. This lever rests partly on a spiral spring at *d*, and is also supported by two vertical pins, with perfect freedom of motion. The end *e* of the principal lever is attached to a second or small lever *f*, from which a chain *g* extends to the centre, where it works on a drum attached to the arbour of the hand. A hair spring, the attachments of which are made to the metallic plate *i*, regulates the motion of the hand.

As the weight or pressure of the atmosphere is increased or diminished, the surface of the elastic box *a* is depressed or elevated, and this motion is communicated through the levers to the arbour of the hand. The spiral spring on which the lever rests at *d*, is intended to compensate for the effects of alterations of temperature on the minute portion of air which the box must contain, however perfect the exhaustion. The actual movement at the centre of the elastic box, from whence the indications emanate, is very slight, but this is increased 657 times at the point of the hand; so that a movement to the extent of $\frac{1}{22}$d part of $\frac{1}{10}$th of an inch in the box, carries the point of the hand through 3 inches on the dial. The tension of the box in its construction is equal to 44 lbs. At the back of the outer case is a screw, to adjust the hand to the height of a standard mercurial barometer. [See APPENDIX.]

BARYTA. See BARIUM.

BASE, in geometry, is the lowermost part of a figure, and in a solid, the surface on which it rests.

The *base of a room*, is the lower projecting portion, consisting of two parts, a plain board adjoining the floor, called the *plinth*, and above it one or more mouldings, which, taken collectively, are called the *base mouldings*. The plinth ought to be tongued into a groove in the floor, by which the diminution of breadth, caused by the shrinking, does not produce any aperture between its under edge and the floor. The upper edge of the plinth ought to be rebated upon the base.

In chemistry, the substance with which an acid is combined in a salt, is called its *base*. Thus, in sulphate of iron, sulphuric acid is the acid, and oxide of iron is the base. The term *basyle*, is often applied to a body which gives to a base its distinctive character; thus ethyle, is the basyle of ether. The term *radicle*, is applied to a substance which gives to an acid its distinctive character; thus cyanogen is the radicle of hydrocyanic acid.

BASE-LINE. See SURVEYING.

BASKET. A kind of vessel made of osier, wicker, rushes, straw, grasses, twigs, branches, whalebone, &c. of different figures and sizes, according to the purpose it is intended to serve. The ancient Britons were celebrated for their baskets, which were exported in large quantities, and fetched high prices in Rome. The art of interweaving twigs, reeds, &c. is practised among the rudest nations at the present day, and they even excel Europeans in this simple art. In some parts of South America, the natives make rush baskets so closely interwoven as to hold water. Wicker boats covered with skins attracted the notice of the Romans in Britain, and at the present day, basket boats made of split bamboo are used in Hindustan. Houses, cottages, fences and gates of wicker-work are used in different parts of the world. A two-horse carriage of basket-work called a "Holstein wagon," is used in some parts of Europe, and an appendage to stage-coaches, called the *basket*, was formerly made of wicker-work.

The most common substances used for basket-making are osiers or willows. Those of the best kind were formerly imported into Great Britain from France and Holland, but the trade having been interrupted during the long protracted war, the Society for the Encouragement of Arts and Manufactures offered a premium to those cultivators who should raise the greatest quantity, the number to be not less than 6,000 plants on an acre. Mr. Philipps of Ely was one of the successful competitors. According to him the osier, a species of salix, contains many varieties, which may be separated into two divisions, and in each division there is only one variety well adapted for basket-making. In the first division is the grey or brindled osier: this, in common with the others, has a light-coloured leaf, but is distinguished by the bark being streaked with red or blood colour. It grows vigorously, it is very hardy and tough, and bleaches well. All the other varieties are coarse and spongy; they have a thick pith and are very perishable. They are however still used for coarser work, and during the interruption of the continental intercourse were in great request; hence, English baskets fell into disrepute. In the second division is the *Welsh willow*, which is tough and durable but of a bad colour: there are two varieties, the red and the white, the former of which is preferred and forms part of every plantation, from its use in tying up the bundles after they have been barked or whitened. There are other varieties known as the *west country Spaniard*, the *new willow*, the *French* and the *red Kent willow*. The French is the best, especially for smaller and finer work in baskets, fans, hats, &c.: it is extremely taper, pliant, close-grained, tough and durable. Large quantities of it are imported into Great Britain from the continent.

According to Philipps, autumn, not spring, is the proper season for planting willows, and as early in autumn as the cuttings can be taken without injury to the parent stock. The ground is laid out in beds or burrows 18 feet broad with ditches 9 feet wide on each side. The upper surface of the ditches to the depth of 14 inches is thrown on the beds, and the remainder of what is excavated from them is used for turf or fuel. The beds, now consisting of about $2\frac{1}{3}$ feet thick of solid earth above the surface of the substratum of peat, are planted in the autumn, and produce good crops. The plants should not be supplied with too much water, or they will be sickly: they require a considerable degree of humidity, but will nevertheless flourish on comparatively dry soils. The vicinity of water is an essential quality in selecting a spot for a plantation. The sets of osiers should be inserted in regular rows: their age is not of importance, for a vigorous crop may be produced from the root of the oldest tree deprived of its trunk. When the plants have acquired their maturity they are cut and made up into bundles in iron hoops, 36 or 40 inches in diameter, for the market, and are sold in this way or in loads. The plantations require to be well fenced against cattle, which find a favourite food in the shoot and leaf.

In the preparation of osiers for the basket-maker, they are either split asunder or stripped of their bark, according to the kind of work in which they are employed. When stripped, the osiers require to be previously soaked in water, and the stripping is performed by drawing the willows through an iron edged machine called *brakes*, which removes the bark; the osiers are then cleaned by a sharp knife They are next exposed to the sun and air, and are stored in a dry place. The osiers which are not stripped, require to be carefully preserved, and before being used they must be soaked in water. The barked or white osiers are divided into bundles or faggots according to their size; the larger ones being used for the strong work in the skeleton of the basket, and the smaller for the bottom and sides. When the smaller osiers are used for ordinary work, they are taken whole, but for fine work each osier is divided into *splits* and *skains*. Splits are osiers cleft into four parts by an implement consisting of two edge tools placed at right angles, which divide the rod longitudinally down the pith. These are next drawn through an implement resembling the common spoke shave, keeping the grain of the split next the wood or stock of the shave, while the pith is presented to the edge of the iron, which is set in an oblique direction to the wood; and to make the split more regular, it is passed through an *upright* or flat piece of steel with a cutting edge like an ordinary chisel. The flat is bent round, so that the two edges approach at a greater or less interval, by means of regulating screws, and the whole is fixed into a handle. By passing the splits between the two edges, they are reduced to skains, the thickness of which is determined by the interval between the edges of the tool. The basket maker is furnished with a few simple tools, such as knives, bodkins and drills for boring, leads for keeping the work steady, and a heavy iron beater, for beating the work close as it increases in size.

Basket-work is a coarse kind of weaving, in which the long osiers form the warp, and those which are twined in, or interlaced therewith, the woof. In making an ordinary basket, the length of the osiers selected for the purpose is considerably greater than that of the finished work. The proper number is arranged on the floor in pairs parallel to each other, in the direction of the length or warp of the basket. These parallel rods are then crossed at right angles by two of the largest osiers, with the thick ends towards the workman, who places his foot on them, and weaving each alternately over and under the parallel pieces first laid down, they are thus confined in their places. In this way the foundation of the basket, called the *slat* or *slate*, is formed. The long end of one of the two rods is next taken and woven under and over the pairs of short ends all round the bottom until the whole is woven in. The same is done with the other rod, and then additional long osiers are woven in until the bottom is of sufficient size. The slat being thus finished, the superstructure is raised by first sharpening the large ends of as many long and stout osiers as are required to form the ribs or skeleton. These are forced or plaited between the rods of the bottom, from the edge towards the centre, and are turned up in the direction of the sides. Then other rods are woven in and out between each of them until the basket is raised to the intended height. The edge or brim is finished by turning down the projecting ends of the ribs whereby the whole is firmly and compactly united. A handle adapted to the work is formed by forcing two or three osiers, sharpened at the end, and cut to the proper length, down the weaving of the sides close together, and they are pinned fast about two inches from the brim, so as to retain the handle in the proper position. The osiers are then bound or plaited, and the handle is finished.

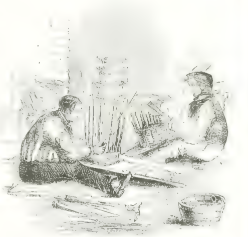


Fig. 164.

Such are the simple processes concerned in making an ordinary basket. Other baskets differ only in having finer materials and nicer workmanship. The skains are frequently smoked and dyed either in dull or brilliant colours, and the taste of the workman is shown in their proper mixture.

The facility of teaching and acquiring the art of basket-making, renders it a favourite employment for the blind in the asylums established for their reception.

The bine of the hop, with the flowers and leaves removed, has been lately employed as a material for basket-making or wicker-work. A patent was taken out by Mr. Reynolds, in 1847, for this employment of an article previously considered useless.

BASSORINE. See Gum.

BATHS. Places constructed purposely for the washing of the body in hot, cold, or tepid water, a practice, the salubrity of which was well understood by the ancients, as it is by some modern nations, but which has been greatly overlooked in our own country until very recently, when it has begun to be better appreciated, and to receive something like a due share of attention. It is scarcely to be wondered at, that eastern nations should exalt ablution and bathing to the rank of religious observances, for where the heat renders perspiration copious, frequent bathings are not only means of pleasure and refreshment, but absolute and necessary duties of life. And even in cold, or in perpetually varying climates like our own, although bathing cannot be so freely indulged in, especially by invalids, yet the functions of the skin cannot be preserved in healthful activity, nor the changes of climate effectually guarded against, without the frequent use of the bath. A clever writer on Physiology says, "The warm, tepid, cold, or shower bath, as a means of preserving health, ought to be in as common use as a change of apparel, for it is equally a measure of necessary cleanliness. Many, no doubt, neglect this, and enjoy health notwithstanding; but many, very many, suffer from its omission, and even the former would be benefited by employing it."

At Athens, and in Rome, baths were in common use; in the latter, during the Augustan age, they were so luxuriously built and furnished, as to call forth the reproof of philosophers. According to Seneca, private baths were constructed with the utmost magnificence, so that even among plebeians, that person was held to be poor, or sordid, whose baths did not shine with costly marbles and precious substances, enclosed within richly decorated walls, and supplied with water from silver pipes. The public baths were at least sixteen in number, and of great magnitude and beauty, containing large halls for bathing and swimming, others for athletic games, others for public lectures and conversations. All these fine rooms were lined and paved with marble, and furnished with paintings, statuary, collections of books, &c. These baths were called *Thermæ*, which means "warm waters," and are now all in ruins. The suite of rooms more immediately appropriated to bathing, included an *apodyterium*, or room for undressing; an *unctuarium*, for the ointments; a *sphæristerium*, or room for exercises; a *calida lavatio*, or warm bath; a *laconicum*, or hot room for sweating; a *tepidarium*, or warm room with a tepid bath; and a *frigidarium*, which contained the cold bath. The public baths of Rome were constructed at a vast expense, and principally for the use of the poorer classes, though frequently resorted to by all ranks: they were named after the emperors, and those of Titus, Diocletian, and Antoninus Caracalla, are still in sufficient preservation to give a tolerable idea of their former grandeur. The last named were 1,500 feet long, by 1,250 broad, and at each end were temples, one to Apollo, the other to Esculapius, the tutelary deities of the place.

It is a gratifying feature of our own times, that the care for the health and comfort of the working and poorer classes, which was long ago exhibited by a heathen nation, has now taken deep root among ourselves, so that the erection of public baths and washhouses is a matter in which numbers of influential persons feel a lively interest. The first attempt of this sort in the metropolis, appears to have been that of a society of small means, established in 1844, and called an "Association for promoting Cleanliness among the Poor," which commenced operations in Glasshouse Yard, near the London Docks, and met with such success, as to lead to the formation of a more important association, and eventually to the bringing in of a Bill in Parliament, for the furtherance of the object. Since that time, several large establishments have been opened, in which private baths, both hot and cold, and also swimming baths, can be enjoyed at a very low charge; and where, in another department, the wives and daughters of labouring men are allowed to wash, dry, and iron their linen, at the rate of a penny an hour, and with conveniences and accommodations they had previously little notion of. This system has been also extended to the provinces, and it is not uncommon in manufacturing districts, to find special provisions made for the work-people in this respect, by their enlightened and benevolent masters. Contemporaneously with this increased attention to means of bathing for the lower classes, there has been a greater desire for accommodation of the same kind in the dwellings of the rich. Modern houses, not only of the first, but of the second and third class, now frequently include a bath-room, where the means of enjoying a warm bath are afforded, without much trouble to the inmates.

In the construction of baths several materials are employed, according to the taste and means of the proprietor. The best is undoubtedly marble, in the form of slabs, properly imbedded in cement, and forming a lining to a wooden case. This is expensive, and also weighty, and, if of white marble, is liable to get discoloured in time; but it is a very handsome and permanent kind of bath. Sometimes Dutch or earthenware tiles embedded in cement are used instead of marble, and answer very well if they can be kept water-tight, which is difficult. A very general material for baths is however found in either copper, zinc, or tinned iron. These are covered with several coats of paint and marbled. As a substitute for a better kind of bath, wooden tubs are sometimes used, but these soon contract a mouldy smell, and are also troublesome from their liability to shrink. The proper situation for a bath must be regulated by the convenience of the owners, but it is very desirable not to place it in the basement story, on account of a chilly and damp feeling which nearly always pervades the lowest rooms of a house. Yet this situation for the bath is not unfrequently chosen. In the better class of private houses, warm-baths are situated in the dressing-rooms adjoining the principal bed-rooms, or there is a separate bath-room on the bed-room floor. This should have proper means of ventilation, or a damp odour will soon be observed, and the walls will suffer from the moist atmosphere. Many modern houses possess the great convenience of a water cistern at the top, supplying the rooms without labour. In this case the bath is easily and adequately supplied, and if there happen to be a laundry at the upper part of the house, or convenient place for erecting a copper, this, by means of feeding pipes, would supply hot water to the bath. Another contrivance consists in carrying a pipe from a higher level than the bath-room down to the kitchen, and allowing it to repose in a coil within the boiler, from which the pipe is continued, and ascends to supply the bath. The cold water contained in the coiled part of the pipe becomes sufficiently heated by lying in the boiling water to supply a warm-bath; but it is only when the boiler is kept hot by a large fire that this is found to answer. Sometimes a boiler is placed behind the fire place in the dressing-room; but this is objectionable, from the escape of steam which sometimes takes place, and from danger of the flues becoming choked with soot and taking fire. Another and safer method is the following:—"A wagon-shaped boiler, holding about six gallons of water, is properly placed over a small furnace, in any convenient and safe part of the house, as the kitchen, scullery, servants'-hall, or wash-house. The bath itself, of the usual dimensions and construction, is placed where it is wanted, with a due supply of cold water from above. Two pipes issue from within an inch of the bottom of the bath, at its opposite extremities: one at the head of the bath, about one inch, and the other at the foot, an inch and one-eighth in diameter. These tubes descend to the boiler, the smaller one entering it at the bottom, and the larger one issuing from its top. Under these circumstances, supposing the pipes and boiler everywhere perfectly tight, when the bath is filled, the water will descend into, and expel the air from, the boiler, and completely fill it. Now, upon making a gentle fire under the boiler, an ascending current of warm water will necessarily pass upwards through the larger pipe which issues from its top, and cold water will descend by the pipe which enters at the bottom; and thus, by the establishment of currents, the whole mass of water in the bath will become heated to the desired point, or, if above it, the temperature may easily be lowered by the admixture of cold water." The quantity of fuel required for this kind of bath is very small, as is the time occupied in heating it; but two or three things have to be observed in using it. As soon as the water is sufficiently hot, the fire should be put out, or there may be an unpleasant increase of heat while the person is in the bath. Care should also be taken never to make so fierce a fire under the boiler as to cause the water in it to boil; for, in this case, the steam rising to the top, and condensing in the pipe, occasions violent concussions, which are very apt to injure the pipes, while they also cause alarm to the inmates of the house.

Baths are sometimes heated by steam; but this is more suitable for public than private establishments. Tinned iron or copper baths are also sometimes constructed with an outer case, in which water flows, and is made hot from a furnace at one end, thus heating the whole mass within the bath. The simplest of all contrivances for large establishments is that first alluded to, and which may be employed on a very large scale. A large boiler connected with the cistern, placed above the level of the baths, affords the means of drawing hot water in any quantity directly into the baths. Hot water should enter the bath by a pipe of 1½ inch diameter, and cold water the same; and every bath should have a 2 inch waste-pipe, opening about two inches from the top of the bath, so that when the person is immersed, or the pipes are inadvertently left open, there may be no danger of an overflow.

BATTEN. A scantling of stuff from 2 to 6 inches broad, and from $\frac{5}{8}$ths to 2 inches thick. Battens are used in walls to secure the laths over which the plaster is laid. Before fixing the battens, equidistant bond timbers are either built in the wall, or the wall is plugged in equidistant points. The plugs are generally placed at the distance of 1 foot or 14 inches from centre to centre in the length of the batten. Battens upon exterior walls, quarters in partition walls, the ceiling and bridging joists of a naked floor, also the common joists for supporting the boarding of a floor, are fixed at the same distance, namely, from 11 to 12 inches in the clear. When battens are fixed against flues, iron holdfasts are employed instead of bond timbers or plugs. When attached to a wall, they are generally fixed in vertical lines. Great care should be taken to regulate the faces of the battens, so as to be as nearly equidistant as possible from the intended surface of the plaster. The act of fixing battens to walls is called *battening*, but in floors it is called *furring*. Every piece of masonry or brick work which is not sufficiently dry should be battened for lath and plaster. When the windows are boarded, and the walls of a room not sufficiently thick to contain the shutters, the surface of the plastering is brought out, so as to give the architrave a proper projection, and quarterings are used for supporting the lath and plaster instead of battens. The same is also done when the breast of a chimney projects into the room, in order to cover the recesses, and make the whole side flush, or all in the same surface with the breast.[1]

BAY-SALT. See SALT.

BEAM, in building, is a piece of timber or metal used for sustaining a weight or counteracting two equal and opposite forces, either drawing or compressing it in the direction of its length. When employed as a lintel, it supports a weight; when used as a tie-beam, it is drawn or extended; and, as a collar-beam, it is compressed. "The word beam is most frequently subjoined to another word, used adjectively, or in apposition, which shows the use, situation, or form of the beam: as *tie-beam*, *collar-beam*, *dragon-beam*, *straining-beam*, *camber-beam*, *hammer-beam*, *binding-beam*, *girding-beam*, *truss-beam*, *summer-beam*, &c. Some of these are also used simply, as *collar*, instead of collar-beam; *lintel*, instead of lintel-beam; *girder*, instead of girding-beam; *summer*, instead of summer-beam. Lintels and girders are almost constantly used simply, and *bressummers* and *joists* are never used in composition."—*Nicholson.*

BEAVER. See HAT.

BEER. At nearly all periods in the world's history, and among nearly all nations, the art of making a fermented drink from some kind of grain appears to have been known. Of all the cereals, barley is best adapted to the making of beer, and it is curious to notice how early this experimental fact was discovered. Herodotus, who wrote about 450 years B.C., states that the Egyptians made their *wine*, as he calls it, from barley, because they had no vines.

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(1) Nicholson's Architectural Dictionary.

The Greeks also called their beer [illegible]. Dioscorides describes two kinds of beer made from barley. Tacitus states that, in his time, beer was the common drink of the Germans, as it is at the present day. Pliny says, that all the nations of the west of Europe make an intoxicating liquor of corn and water. "The manner of making this liquor, is sometimes different in Gaul, Spain, and other countries, and is called by many various names; but its nature and properties are everywhere the same." Isidorus and Orosius, describe the mode of manufacture adopted by the ancient Britons and other Celtic nations:—"The grain is steeped in water and made to germinate, by which its spirits are excited and set at liberty; it is then dried and ground, after which, it is infused in a certain quantity of water; which being fermented, becomes a pleasant, warming, strengthening, and intoxicating liquor." A better definition of beer could scarcely be given at the present day.

The curious and even complicated processes of brewing, have thus been in operation during several thousand years, but it has only been within our own time that chemical science has enabled us to comprehend them. It will be seen by reference to the article BREAD, that most seeds contain a considerable portion of the well-known nutritive substance STARCH or *fecula*. When seeds begin to germinate, a peculiar azotised substance named *diastase* (from διΐστημι, I separate) is formed, which possesses the remarkable property of converting the starch into a fermentable sugar resembling cane-sugar, but not identical therewith. This change does not, however, immediately take place, for the starch is first changed into a gummy mucilaginous substance, largely soluble in water, named *dextrine*, from the action of its solution upon a ray of polarised light, in causing the plane of polarization to turn to the right, while a solution of common gum causes a deviation in the opposite direction. Dextrine does not ferment by the addition of yeast; but by the action of diastase, it is readily converted into starch sugar, which is fermentible.

Preparatory to the process of brewing, the barley is converted into malt by being made to germinate up to a certain point, at which the proportion of diastase is largest; the vitality of the young plant is then destroyed by heat. The operation of a high temperature also serves another useful purpose, for it has been found that when starch is carefully heated up to a point when vapour rises from it, it loses its gelatinous character and becomes converted into dextrine. In the kiln-drying of malt, a portion of the starch, therefore, undergoes this change. In the first process of brewing, namely, infusing or *mashing* the malt with hot water, the starch or dextrine of the grain is converted into sugar by the action of the diastase, the quantity of which, in malted barley, scarcely exceeds 1 part in 500. A solution of diastase has no remarkable action on most vegetable principles, but on starch it exerts a specific action, converting it first into dextrine and afterwards into starch-sugar. The change of starch into dextrine by the action of diastase, takes place in gelatinous starch even at the freezing point of water; but the conversion into sugar is most powerful between 150° and 160°. At the boiling point of water, diastase ceases to act on starch. So powerful is the action of diastase at proper temperatures, that 1 part is said to be sufficient to saccharify 2000 parts of dry starch; but the larger the proportion of diastase the quicker the change. Thus, Messrs. Payen and Persoz, by the action of diastase, converted starch into dextrine or sugar according to the temperature of the mixture and the duration of the process. In a mixture of from 6 to 10 parts of pale malt, 100 of starch, and 400 of water, the starch was converted chiefly into dextrine, in from 20 to 30 minutes, at the temperature of 158°; but at the temperature of 167° the starch was almost entirely converted into sugar in the course of 2 or 3 hours.

These details throw great light upon the ancient arts of malting and brewing, and will, doubtless, assist the reader in following the practical details which we are now about to enter upon.

The principal substances concerned in the manufacture of beer are two; the one to form the sugar, and consequently the alcoholic portion of the liquor; the other to communicate a particular flavour, and also to assist in its preservation. The experience of mankind has led to the choice of barley for the first object and hops for the second. But instead of barley, any of the cereals, such as wheat, oats, maize, rice, &c., are fitted for the purpose, in consequence of the quantity of starch contained in them, and occasionally other vegetable bitters are substituted for hops.

There are two species of barley, *Hordeum vulgare* and *Hordeum hexastichon*. In the first or common barley, two seeds are arranged in a row on its spikes; and in the other, three seeds form a point, so that its double row has apparently six seeds. It is a hardy plant, better adapted to cold climates than common barley; it is largely cultivated in Scotland under the name of *bear* or *big*. The finest barley is grown in mild climates, and hence the barley of Norfolk and Suffolk has a denser and larger grain and a thinner husk than that of Scotland. When barley is converted into malt, a change takes place, which is represented in the following comparative analysis by Dr. Thomson. 100 parts of barley and 100 parts of malt contain respectively—

	In 100 of Barley.	In 100 of Malt.
Gum . . .	5	14
Sugar . . .	4	16
Gluten . . .	3	1
Starch . . .	88	69
	100	100

But according to Proust, barley also contains a peculiar substance, not soluble in hot water, which he terms *hordein*, and which during malting is diminished in quantity and converted into starch or sugar. Hitherto, hordein appears to have been confounded with starch. His comparative analyses are—

	In 100 of Barley	In 100 of Malt
Resin	1	1
Gum	4	15
Sugar	5	15
Gluten	3	1
Starch	32	56
Hordein	55	12
	100	100

Hops are the seed pods of the female plants of the *Humulus lupulus*, a creeping plant of the family Urticeæ. It is cultivated in considerable quantities in Kent, Sussex, and Hampshire. The active part of the plant called *lupulin*, which is alone useful in making beer, is a yellow aromatic dust occurring at the base of the hop-flowers or cones. It consists of an essential oil, a resin, an azotised substance, sulphur, silica, chloride of calcium, sulphate and malate of potash, phosphate and carbonate of lime, and oxide of iron. This powdery secretion forms ⅛th of the weight of the flowers. It can be easily collected by drying the flowers at the temperature of about 86° and shaking them in a coarse canvass bag. Of the complicated analysis of this dust, the volatile essential oil, which forms 2 per cent. of the total weight of the hop, is the most essential part.

The cones are gathered before they are scarcely ripe, for which purpose the plants are cut about 3 feet from the ground, and the cones carefully picked off one by one. Those that are too ripe or defective are separated from those that are just ripe enough, and both kinds are carried to the kiln as soon as possible after they are picked. The heat of the kiln must be carefully regulated, to prevent the essential oil from being evaporated. The heat should not exceed 86° Fahr. In many cases the kiln has two floors, on the uppermost of which the greener hops are spread and gradually dried before they are subjected to the greater heat of the lower floor. Charcoal is the only kind of fuel which is found not to injure the flavour of the hops. They are considered sufficiently dry when they become crisp; but their brittleness is removed by allowing them to reabsorb a little moisture in the storehouse before being packed. 5lbs. of moist hops weigh only 1lb. when taken from the kiln. The good qualities of the hops can only be retained by excluding them from the air, for which purpose they are strongly compressed by means of a hydrostatic press, and packed in sacks of fine canvass called *pockets*, which weigh about 1½ cwt. each. The stronger and darker coloured hops are packed in coarse canvass *bags* weighing about 3 cwt. The former are used chiefly by the ale brewer, and the latter by the porter and beer brewer.

The number of acres of hops in England, in 1859, was 15,655; the number of pounds weight charged with duty in 1859 was 68,196,958; 1,353,075 lbs. of British hops were exported, and 2,220 cwt. were imported and retained for home consumption. The duty on British hops is at the average rate of 1*l*. 2*s*. 5¼*d*. per acre. The total amount of duty for the year 1859 was [illegible].(1)

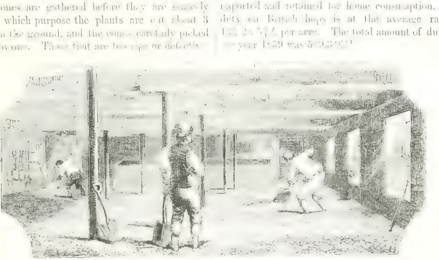

Fig. 105. STEEPING, COUCHING, AND FLOORING MALT.

The conversion of barley into malt is generally a distinct occupation from that of brewing. It consists of four processes, namely, *steeping*, *couching*, *flooring*, and *kiln-drying*. In the first process the barley is thrown into a square cistern lined with stone, and sunk at one end of the malt barn, Fig. 105. It is placed as evenly as possible upon the floor of the cistern, and a quantity of water is let in sufficient to cover it. The water is often introduced before the barley, and it is customary to draw off this water and introduce fresh during the steeping, to prevent anything like fermentation. The law requires that the barley shall remain in the cistern at least 40 hours, but in cold weather a much longer period is often required.

During the steeping, the barley imbibes moisture and increases in bulk; it also evolves carbonic acid, nearly all of which remains in solution in the water; a portion of the husk or skin of the grain also becomes dissolved, thereby imparting a yellow colour and a particular odour to the water. The quantity of water absorbed by the grain depends upon the goodness of the barley, and the time employed in steeping. Dr. Thomson states the general average to be 0.47; or 100 lbs. of barley steeped the usual time, weigh, when taken out of the steep and dried, 147 lbs. English barley acquires more weight than Scotch barley, and this more than big. While the barley is in the steep cistern it is gauged by the exciseman, and the duty on the malt is levied by what is called the best gauge, or that which gives the greatest bulk of grain. Dr. Thomson has known Suffolk barley to swell from 100 to 183. This was the greatest he ever observed; the smallest was from 100 to 109, which took place in Perth big.

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(1) Parliamentary Paper.

As the steep-water becomes of a yellow colour, the grain becomes whiter, and so soft that the two ends of a grain can be squeezed together between the finger and thumb. The water is then let off, and the grain allowed to drain. It is then thrown out of the cistern upon the malt floor, and arranged in a regular rectangular heap called the *Couch*. Here it is again gauged by the exciseman, and if it measure more than it did in the steep, he can charge an increased duty. The grain remains in the couch about 26 hours, during which time it gradually increases in temperature, and parts with its moisture. In about 96 hours after being thrown out of the steep, it is about 10° higher than the temperature of the surrounding air. It exhales an odour resembling that of apples; it feels warm and moist if the hand be thrust into it. This moisture is called *sweating*, and on examining the grains in the interior of the heap, it will be found that germination has commenced. Small roots appear at the bottom of each seed, having at first the appearance of a white prominence, which soon divides into three or more rootlets, which rapidly increase in length unless means be taken to check their growth, and in doing so consists the principal art of the maltster. The temperature is lowered, and the growth of the roots checked by the operation of flooring or spreading the grain thinner upon the floor, and turning it over carefully several times a day (see Fig. 105), so as to keep it at the temperature of about 62°. For this purpose the depth of the layer, which at first is 16 inches, is diminished a little every time the grain is turned, till at length the depth is only 3 or 4 inches. About a day after the sprouting of the roots, the rudiments of the future stem, called by the maltsters *acrospire*, begin to appear. It rises from the same extremity of the seed with the root, and advancing within the husk would, if the process were continued, at length issue from the other extremity in the form of a green leaf, but the process is stopped before it has made such progress. During this process the grain absorbs oxygen, and emits carbonic acid; and the temperature rises to about 70°, and in some cases even to 90°. The appearance of the kernel or mealy part of the corn undergoes considerable change. The glutinous and mucilaginous matter in great measure disappears, the colour becomes whiter, and the texture so loose that it crumbles to powder between the fingers. When the acrospire has come nearly to the extremity of the seed, the process is stopped, and the object of malting has been accomplished. The time usually occupied in this process of couching is about 14 days.

The germination of the malt is stopped by drying upon a kiln, which consists of a chamber, floored with an iron plate full of holes, and furnished with a vent in the roof for the escape of fumes. Below this floor is a furnace containing charcoal or coke, and the heated air ascends through the holes of the floor, and then through the malt, as in Fig. 106.

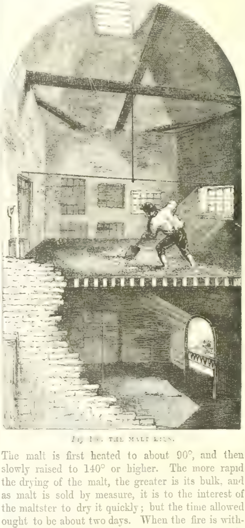

Fig. 107. THE MALT KILN.

The malt is first heated to about 90°, and then slowly raised to 140° or higher. The more rapid the drying of the malt, the greater is its bulk, and as malt is sold by measure, it is to the interest of the maltster to dry it quickly; but the time allowed ought to be about two days. When the fire is withdrawn, the malt is allowed to remain until it is nearly cold. In this process the roots of the grain, or *cornings*, as the maltsters term them, dry up and fall off, and are separated by allowing the malt to fall from the floor above through shoots, the ends of which are represented in the ceiling of Fig. 107, into a wire screen, the wires of which are set too close to allow the grain to pass through. To delay the progress of the malt down this screen, boards are placed crosswise at a short distance from the wires; and the workman, by agitating the malt with a stick, further assists the separation of the radicle. The malt is then spread out to *mellow*, or to become soft and mealy by a slight absorption of moisture.

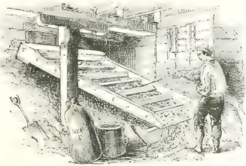

Fig. 107. CLEANING MALT.

After this malting, drying, and cleaning, Dr. Thomson found that 100 lbs. of barley originally employed will weigh on an average 80 lbs.; but if the raw grain be kiln-dried at the same temperature as the malt, it will lose 12 per cent. of its weight. Hence the real loss of weight sustained by barley in malting amounts to 8 per cent.; which is thus accounted for:—

Carried off by the steep-water	1.5
Dissipated while on the floor	3.0
Roots separated by cleaning	3.0
Waste	0.5
	8.0

The waste arises from grains of malt crushed by the workmen while turning the malt on the floor. Big sustains a much greater loss of weight when malted than barley.

The bulk of the malt is greater than that of the barley from which it is obtained, but the amount varies with the goodness of the grain, and the method of kiln drying. According to the same authority, 100 bushels of the different kinds of grain gave on an average the following results:—

English barley	109
Scotch barley	103
Scotch big	100.6

Good malt should be large, clean, plump, and unshrivelled in the grain; the skin should be thin, and the grain should be lighter than water. The acrospire should be seen to extend scarcely more than three-quarters through the length of the husk. The grains should break without difficulty, and disclose a full, flowery, mellow kernel, which if drawn across a board, leaves a chalky trace. No part of the kernel should be hard or horny. The taste should be sweet and mellow. The colour is pale and bright, and the odour agreeable.

The quantity of malt charged with duty in the year 1859, in the United Kingdom, was 5,163,010 quarters; there were also 659,882 quarters free of duty for distillers. The quantity used by brewers, &c., was 4,866,402 quarters.

The varieties of malt known as *pale*, *amber*, and *brown*, can be produced from the same kind of malt by varying the temperature of the drying. Pale malt is dried at the proper temperature, and produces the strongest and best beer. Amber coloured malt is scorched, and in brown malt the scorching is carried to its utmost limit. Indeed this scorching is so wasteful a process, that where the object is only colour, it is better to mingle amber or brown malt with pale malt in proportions adapted to the required tint. The distinction between the terms *ale* and *beer* or *porter*, arose from the colour of the malt used in brewing, pale malt having been used for the former, and brown malt for the latter. The brown malt from its partial charring had acquired a bitter taste, which it communicated to the beer together with a dark colour, and being agreeable to the palate, and less exciting than ale, it became the favourite beverage of the common people, especially in the metropolis.[1] But when heavy taxes were imposed upon malt, the brewers discovered that a much larger quantity of wort of a given strength could be prepared from pale malt than from the brown. The consequence was that porter changed its character; for it was brewed from pale malt, and coloured with brown malt; while to imitate the pleasant agreeable bitter of the genuine porter, quassia, cocculus indicus, and other substances were employed. By the act 56th Geo. III. c. 58, no brewer is allowed to use or have in his possession any substance whatever for the purpose of darkening his worts or beer, except brown malt; nor is he allowed to mix with his worts or beer any molasses, honey, liquorice, vitriol, quassia, cocculus indicus, grains of paradise, Guinea pepper or opium, or any article or preparation whatsoever, for, or as a substitute for malt or hops, under the penalty of forfeiture and 200*l*. for each offence, and any person selling the same to a brewer for such purpose is liable to a penalty of 500*l*. By the act 1st Will. IV. c. 51, for repealing the ale and beer duties, the use of unmalted corn or grain, with malted, is forbidden under a penalty of 200*l*.

Brewing consists of six processes, namely, *grinding the malt*, *mashing* or infusing with hot water, *boiling* the wort with the hops, *straining*, *cooling*, *fermenting* with the addition of yeast, and *clearing*, storing, &c.

The malt should be ground, or rather crushed into a coarse powder, for if finely ground like flour, the hot water would cause it to set or coagulate into lumps, and thus prevent a large portion of it from being wetted at all. Two horizontal circular stones, such as are used in grinding flour, are sometimes used, but it is not possible to regulate the distance between them, so as to prevent some of the grains from being ground to flour, while others escape almost untouched. Steel mills which cut the grains by means of teeth something like coffee mills are also used; they are preferable to mill-stones, but grind the malt too much. The best contrivance is a pair of case-hardened iron rollers, regulated at such a distance apart, that the grains in passing through them are bruised only, not cut or ground.

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[1] According to Malone, before the year 1730, the malt liquors in general use in London were *ale*, *beer*, and *twopenny*, and it was customary for the drinkers of malt liquor to call for a pint or tankard of half and half, that is, a half of ale and half of beer, a half of ale and half of twopenny, or half of beer and half of twopenny. In course of time it also became the practice to call for a pint or tankard of *three threads*, meaning a third of ale, beer, and of twopenny; and thus the publican had the trouble to go to three casks, and turn three cocks for a pint of liquor. To avoid this inconvenience and waste, a brewer of the name of Harwood conceived the idea of making a liquor which should partake of the same united flavours of ale, beer, and twopenny. He did so, and succeeded, calling it *entire* or *entire butt*, and as it was a very hearty and nourishing liquor, it was very suitable for *porters* and other working people. Hence it obtained the name of *porter*.

The water being heated to about 160° or 170° in a large copper, is drawn off into a mash tun situated at a lower level. When the water has cooled down to about 160° or under, a quantity of crushed malt is shaken in, sufficient to absorb nearly the whole of the water when thoroughly stirred up with long poles called oars, or by means of stirrers within the mash tun moved by machinery (Fig. 109). The quantity of water ought to be [illegible], and to cause it to swell considerably, so as completely to dissolve the sugar formed during the malting, and to allow the diastase to re-act upon the starch, which until now has remained unchanged. It has even been recommended to use the first portion of water at so low a temperature as 140°, in order to prevent any thing like coagulation in the starch. When the first water has thoroughly saturated the malt, and been left to repose for about half-an-hour, a second quantity of water at 194° may be introduced, and the mixture well stirred up. This mixture of water at 140° and 194°, forming a mean temperature of 167°, is most favourable for the action of the diastase. The mash tun should be covered up and left during two or three hours. The clear infusion of *sweet wort* as it is now called, is then drawn off into a vessel called an *underback*, situated at a lower level than the mash tun. This first infusion having carried off the greater portion of the sugar, and saccharified nearly all the starch; the temperature of the water for the next or *second mash* as it is called, may be as much as 194°. This, mingling with the cooled malt, is reduced to 176°. When this infusion is drawn off, it is added to the first.

Fig. 108. THE [illegible].

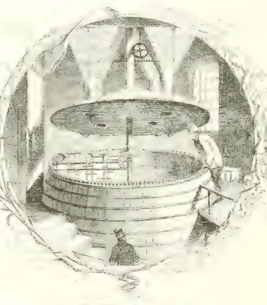


Fig. 109. THE MASH TUN.

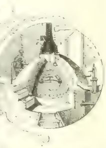


Fig. 110. THE COPPER.

In the third mash, the water, which is near the boiling-point, removes all the remaining soluble matter, and leaves in the mash tun the ligneous pellicle or husk of the malt, a portion of coagulated albumen, and some foreign insoluble matters. This third infusion is not usually added to the first, but it is used for making small beer, or for wetting new malt.

The quantity of water employed for mashing depends, of course, on the greater or less strength of the worts. After the wort is drawn off, the malt retains about 32 gallons of water for every quarter of malt used. In the subsequent boiling and evaporation from the coolers 40 gallons of water are dissipated for every quarter of malt, making 72 gallons loss of water in all; so that if 13 quarters of malt be taken to make 1,500 gallons of beer, 2,400 gallons of water will be required for mashing.

In order that the wort may flow off clear, the mash tun is furnished with a false bottom, raised a few inches above the ordinary wooden bottom of the vessel, and composed of metal plates, lying closely together, and fitting the tun perfectly all round. These plates are perforated with numerous funnel-shaped holes, the widest part being downwards, and the hole in the upper surface too small to allow the grain to pass through. The cock for draining off the wort, or *setting the tap* as it is called, is placed in the tub between the two bottoms.

The first wort ought to be of the colour of the malt from which it is extracted; of a heavy sweet taste, and more delicate in flavour than the succeeding worts, because the water was not sufficiently hot to bring away the coarser and more disagreeable parts of the grain. On this account the first wort is sometimes reserved for superior ales, and the second and third for inferior beers.

In order that the brewer may be able to brew beer of the same quality, it is necessary for him so to regulate the strength of his worts, or in other words, the quantity of saccharine matter in the same measure of water, that they may be at all times identical. As the same weight of malt does not always afford the same quantity of sugar to the worts, he mingles the worts of the different mashes, according to certain proportions which are indicated to him by means of an instrument called a *saccharometer*, which is one of the numerous forms of HYDROMETER used in the arts. It consists of a hollow copper ball A, Fig. 111, with a flat brass stem *c d*, and a weight *a* of the same metal attached to the foot stalk *g h*; the weight *a* so adjusted that the instrument shall sink in distilled water at the temperature of 62° to the point *b* of the scale *c b*, which is divided into 10 equal parts. A barrel (36 gallons) of pure water at 62° weighs 360 lbs. avoirdupois, and the instrument is so regulated that if put into a liquid weighing 361 lbs. per barrel, it would rise to the mark *c*. Each of the divisions between *c* and *b* will therefore represent tenths of a pound. A number of weights, with holes in their centres, marked 1, 2, 3, 4, 5, 10, 20, and 30, accompany the instrument; these represent respectively pounds weight, and are placed as required on the top of the stem, and rest on the projection *d*. If, for example, in putting on the weight marked 10, the instrument sinks in a wort to the point *b*, a barrel of that wort at 62° would weigh exactly 10 lbs more than a barrel of pure water. If the instrument cut the surface at two of the divisions below the point *b*, a barrel of the liquid would weigh 10.2 lbs more than a barrel of water, or 370.2 lbs. But the brewer in speaking of his worts does not take into account the weight of the water; thus a barrel of wort weighing 370 lbs. is spoken of as a ten pound wort, and in this way all his calculations are made. The following are examples:—

Fig. 111.

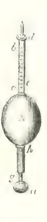
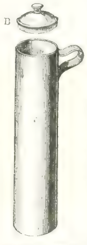


Fig. 112.



	Barrels		lbs. gravity.		
The 1st wort	12	at	35	=	420
2d ,,	14	at	20	=	280
3d ,,	14	at	6	=	84
	40	at	19.6 av.	=	784

or 40 barrels of wort, which, if mixed together, would average 19.6 lbs. per barrel. This would be too weak for ale, and too strong for small beer. Suppose the worts to be mixed in other proportions, such as,

	Barrels		lbs. gravity.		
1st wort	12	at	35	=	420
2d ,,	7	at	20	=	140
Strong ale	19	at	29.4	=	560

There will therefore remain,

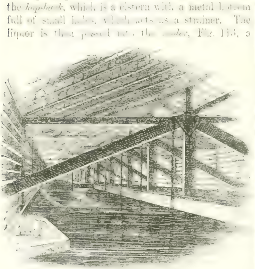
2d wort	7	at	20	=	140
3d ,,	14	at	6	=	84
Small beer	21	at	10.6	=	224

C, Fig. 112, is an assay jar, furnished with a cover B, and is used for containing the wort which is to be weighed by the saccharometer.

When the worts are graduated to the proper strength, they are pumped from the underback as quickly as possible into the copper, which is usually a close vessel with a valve at the top (Fig. 110), loaded so that steam cannot escape at the temperature of 212°. The temperature therefore rises a little above this, when a portion of steam by its increased elasticity forces open the valve and escapes, while the temperature of the wort falls back to 212°. In this way the liquor is concentrated by boiling, and also made clear by the coagulation of the albumen of the barley, which the brewers term *mucilage*. The glutinous matter is also rendered insoluble by combining with the tannin of the hops. As soon as the wort is introduced into the copper, the proper proportion of hops is added, and the two are boiled together until the mixture becomes clear. It is necessary to keep the hops well stirred up during the boiling, to prevent them from settling at the bottom and burning. For this purpose a vertical rod passes into the copper through a stuffing box at the top. This rod terminates in a horizontal bar, carrying an extended chain called a *rouser*, and both are kept in motion by being connected with the moving machinery of the brewery. To prevent the loss of the volatile oil of the hops, a copper pan of water is placed at the top of the boiler, so arranged that the tube which permits the escape of steam and oily vapour passes both into the water, where they are condensed. The water thus impregnated is used in the next mashing.

The quantity of hops depends on the quality of the beer, the time of keeping, the season at which it is brewed, and the climate to which it is to be exported. A larger proportion of hops should be used in brewing in warm than in cold weather, and also if the beer is to be kept a long time or sent to a warm climate. The Kent and Sussex hop is strong and pungent, and is hence preferred by porter brewers; the Worcester hop, being milder and paler, is used for ales. For strong beer, 4½ lbs. of hops to a quarter of malt is sometimes allowed. For the stronger kinds of ale and porter the rule is, in England, to allow 1 lb. of hops for every bushel of malt, or 8 lbs. to the quarter; but for common beer, seldom more than $\frac{1}{4}$ lb. hops to the bushel is allowed.

The boiling being complete, all the bitterness of the hop being extracted, the worts are let down into the *hop-back*, which is a cistern with a metal bottom full of small holes, which acts as a strainer. The liquor is then passed into the *cooler*, Fig. 113, a



[illegible]

shallow [illegible], usually situated at the top of the [illegible] exposed on all sides to a current of air. The cooling ought to be as rapid as possible, to prevent acetification, or, as the brewers term it, *foxing*, for which purpose a horizontal fan, moving rapidly round, creates a powerful draught of air over the surface. A rapid cooling is sometimes effected by passing the wort through long pipes, which are surrounded by large quantities of cold water: this expedites the business of the brewery, and greatly diminishes the risk of foxing.

When the worts are cooled down to 55° or 60°, and in some cases 63°, they are received into the fermenting tun, which is a vast circular vat or tub bound with strong iron hoops and covered in at all parts, except a hole which may be opened to inspect the process or to clean out the tun. A quantity of yeast is then added, varying with the strength of the wort and the season of the year; but in general, 1 gallon of yeast is sufficient to set 100 gallons of wort in complete fermentation. In warm weather the yeast is not added at once; but portions of the worts are let down from the coolers into the fermenting tun at different times, and a small portion of yeast is added each time. With large quantities of wort the temperature often rises very rapidly, and many precautions are required to prevent the fermentation from becoming unmanageable. For the scientific opinions respecting fermentation, we must refer to our article on that subject, but the phenomena of the process as it respects ale, are well described by Mr. Donovan:—"After the mixture of wort and yeast has been made some time, a frothy ring is observed leaving the sides of the tun, and proceeding a few inches towards the centre; and this is succeeded by another and another until at length the whole surface is covered with a thin creamy froth. At the same time a hissing noise, or feeble effervescence is heard, owing to the breaking of innumerable air bubbles on the surface; and there is a small increase of volume, occasioned by involved carbonic acid. Meanwhile the froth rises higher; at first equally, and at length into abrupt elevations resembling *rocks*, as they are called by brewers. The colour of the froth at this period deepens: at first it was white; next it became yellow; and lastly, (although it is better if not,) it often becomes a brownish yellow. The froth is now highest in the middle of the tun, and the fermentation is at its *maximum*. At this time the froth has become more viscid; it holds the carbonic acid more obstinately involved; the bubbles break into each other and form large ones, which in their turn break, and occasion sudden subsidence in different parts of the foamy head. At length the whole head begins to flatten and subside; the middle part, which was the highest, becoming now the lowest; and the fermentation diminishes. The viscid head of yeast becomes more dense; and having parted with its gas, would soon fall down to the bottom of the tun if permitted; but at that period it is skimmed off, and the skimming repeated at intervals, as fast as yeast appears on it. This is done as well to lessen the fermentation as to remove a certain disagreeable bitterness, with which this first yeast is impregnated, and which there is a risk of returning to the wort, were it not now removed."[1]

During this vinous fermentation, a portion of the sugar of the wort is converted into alcohol. When the active fermentation is over, the head formed on the liquor in the tun would, if left to itself, subside; the effervescence would entirely cease; the liquor would become transparent; but after a short time a new set of changes would take place; the acetous fermentation would set in, and the contents of the vat would be converted into vinegar. [See ACETIC ACID.] To prevent this, and at the same time to retain the alcohol, the aroma and bitter of the hop, and the carbonic acid in solution, and to cleanse the beer of the minute particles of yeast which are floating through it and rendering it muddy, the beer is racked off into a number of vessels like hogsheads called the *rounds* (Fig. 114), in which the vinous fermentation is completed. A large quantity of carbonic acid is slowly liberated, which, attaching itself to the suspended particles of yeast, carries them up to the bung-hole, where both are expelled. The bung-hole of each cask is furnished with a sloping tray, which discharges the yeast into a wooden trough, in which the stillions stand (Fig. 114). These stillions are placed in communication with a store tub, which keeps the rounds always full, so that the head of yeast may pass freely over, and keep the body of the liquor in the cask clean.

When the fermentation is over, the beer is either pumped up from the rounds into immense store-vats (Fig. 115), some of which contain upwards of 1,500 barrels, where it is kept until required to be drawn off into casks for consumption, or, in the case of ale, the cleansing is carried on in the casks in which the liquor is afterwards sent out. After the cleansing, the casks are bunged down tightly, so that the carbonic acid, which is still generated in small quantity, may be retained by mechanical pressure in the beverage, and impart to it that sprightliness, sharpness, and foaming head, which are so much admired. It is important to arrest the fermentation while a good deal of saccharine matter remains in the beer, for if this were all expended, there would be nothing to prevent it from passing into the acetous fermentation. It is also of importance to carry the fermentation far enough; otherwise there will be too little carbonic acid generated; the beer will be mawkishly sweet and heavy, from a deficiency of alcohol; and it will be liable to *fretting*, or occasional bursts of weak fermentation, whenever the weather becomes warmer than usual.

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[1] Cabinet Cyclopædia. Domestic Economy, vol. 2.

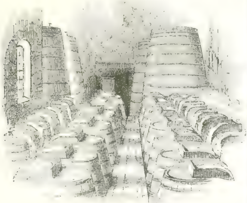


Fig. 111. CLEANSING VATS.

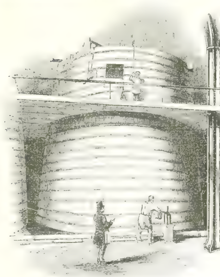


Fig. [illegible]

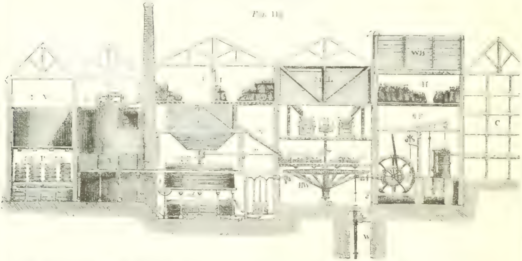
The store cellars should be kept as cool as possible, free from alternations of temperature, vibrations of carriages, &c. The beer is never stationary in its quality, even in the store vats; for as soon as it ceases to improve by the decomposition of its residuary sugar, it begins to degenerate into vinegar. In common strong ale or beer, the proportion of alcohol is about 4 per cent.; in the best brown stout, 6; in the strongest ale, 8; but in common beer, not more than 1 per cent. The nutritive properties of beer depend on its gum, sugar, and starch-gum in solution. It also contains aromatic matters, lactic acid, different salts, and free carbonic acid, the latter varying from 2 to 25 or 26 per cent.

The cleansing is sometimes hastened by means of *finings*: that is, a solution of isinglass in weak sour beer, made from a fourth mash of the same malt, is put into every cask. It forms a kind of web over the surface of the liquor, and gradually sinking to the bottom, carries with it all the flocculent matter, and leaves the beer transparent.

We see, then, that by the process of fermentation the heavy wort has become transformed into a liquid now called beer or ale, of much less specific gravity, in consequence of the dense saccharine solution being partly transformed into a light spirit. This process of *attenuation*, as it is called (from *tenuis*, thin), is carefully watched by the brewer, and measured by the saccharometer, by which means he can judge of the quantity of alcohol formed, and compare it with the amount of sugar which the same instrument indicated to him as present in the worts; he can thus determine the amount of unaltered sugar yet remaining in the beer as its food, and thus judge of the time that it can be kept.

We will now, with the assistance of a diagram, briefly recapitulate the various processes of brewing on a large scale. Fig. 116 is the arrangement of a large porter brewery. The malt is hoisted up from the street by means of a crane, and is stored in spacious granaries or malt-lofts, M L, at the top of the building. Immediately below the granary is the mill M, for crushing the malt, and in the floor below are mill-stones, *m s*, for grinding the malt, when it is required to do so. The crushed or ground malt is conveyed by a trough into a chest, *c*, from which it is raised by the action of a spiral screw into the large chest or bin, B, situated directly over the mash-tun, M T, into which it is let down as it is wanted. The water for the service of the brewery is obtained from the well W by a lifting-pump, worked by the steam-engine S E; a forcing-pipe *f* of the pump conveys water up to the large cistern or water-back, W B, at the top of the engine-house. From this cistern iron pipes are laid to the copper P, and also to every part of the brewery where water is wanted for cleansing and washing the vessels. The copper P can be filled by turning a cock, and the water, when heated, is conveyed by the pipe *p* into the mash-tun M T. It is introduced beneath a perforated false bottom, upon which the malt lies, and, rising up through the holes, comes in contact with the malt. The copper is immediately refilled for a second mash. The wort from the malt is drained off into an underback, *u b*, situated immediately under the mash-tun, from which it is pumped into the copper F, or into a vessel situated above it, by means of the three-barrelled pump along a tube not shown in the diagram. When the water for the succeeding mashes is let out of the copper, the wort is introduced, with the proper proportion of hops, from the hop-loft H. When the boiling has continued a sufficient length of time, the contents of the copper are run off through a large cock into the jack-back, J, which has a perforated bottom to strain off the hops. The hot wort is drawn off from the jack-back through the pipe *a* by the three-barrelled pump, which throws it up into the coolers, C, which are built in several stages, and open at the side, by means of louvers, to the air. When the wort is sufficiently cooled, it is conducted in pipes from all the different coolers to the large fermenting-vessel, F V, in which the first fermentation is conducted. From this vessel the beer is introduced into the rounds, R, where the fermentation is completed, after which the beer is drawn off into immense store vats, where it is kept till wanted. The steam-engine, S E, which gives motion to the machinery, has attached to its large fly-wheel a bevelled cog-wheel, which turns another similar wheel upon the end of a horizontal shaft which extends from the engine-house to the great horse-wheel, H W, which it turns by means of a cog-wheel. The horse-wheel puts in motion all the pinions for the mill-stones and rollers, the horizontal axis which works the three-barrelled pump, and the machinery within the mash-tun for agitating the malt. It also moves a sack-tackle for drawing up the sacks of malt and hops from the court-yard to the top of the building. The hops are kept in their bags and pockets, but the malt is emptied out of the sacks into enormous bins. The horse-wheel, H W, can be worked by horses, should the steam-engine fail, which, however, is a rare occurrence.

Fig. 11.



In one of the London breweries, the quantity of malt wetted during the winter brewing season every Tuesday and Friday is 320 quarters, and on the four other days 230 quarters. There are three coppers of the capacities of 350, 500, and 600 barrels. The coal consumed per day is 10 or 12 tons, and the capacity of the largest store vat is 1,568 barrels. In 1859 the quantity of beer exported from the United Kingdom was 590,782 barrels, of the declared value of 2,042,670*l*.

We have thus indicated the general processes of brewing as they are conducted in a London brewery. They are the same in principle wherever they are carried on. There are, however, variations in practice or in the quality of the materials, in different districts, which afford characteristic differences in the product. The Scotch ale is justly celebrated for its mild flavour and pale colour, more resembling the pale wines of France than any other ales that are brewed in Great Britain, and, like them, it is the result of a lengthened fermentation. The low heat at which the tun is pitched confines the brewing to the colder part of the year, all operations being suspended in the summer months. The Edinburgh brewer is particularly careful in the choice of his malt, and hops, and yeast. He only makes one mash for strong ale, and completes his quantity or *length* of wort by eight or ten subsequent sprinklings or *sparges* of liquor over the goods. These sparges trickle in succession through the malt, and wash out as much more of the saccharine from the mash as may suffice for the intended strength of the ale. The mashing is begun with water at 180° or even 190°, and after working up the malt for half an hour, the whole is covered up, and allowed to infuse about three hours, when it is drained off into the underback. Water at 180° is then sprinkled equally over the goods by being poured upon a circular board swung over the centre of the mash-tun, and, being perforated with small holes, the water descends in a shower. Three or four stop-cocks are inserted in different parts of the bottom of the tun, for drawing off the liquor, in order that it may permeate every part of the goods equally. When the first sparge is run off, which may be in 20 or 25 minutes, a second sparge is [illegible] in; after this a third, and so on, until the length is made up of the proper specific gravity.

The quantity of hops seldom exceeds 4lbs. to the quarter of malt. A little honey and a few coriander seeds, or other aromatics, will assist the flavour. After the boiling, the worts are cooled down as low as 50°, and even 45°. The fermentation is carried on for a fortnight or three weeks. As small a portion of yeast is used as possible, and this is sometimes added in two separate portions; and, to prevent the fermentation from becoming slack, the tun is stirred up or roused twice a day, morning and evening, if necessary. When the fermentation has slackened, the ale is cleansed, or the top barm might re-enter the body of the liquor, and it would become *yeast-bitten*. When the ale is cleansed, the head, which has not been disturbed for some days, is allowed to float on the surface till the whole of the then pure ale is drawn off into casks. After this cleansing there is little or no yeast given off, as nearly the whole of the fermentation has been completed in the tun. The strength of the best Scotch ale varies from 32 to 44 lbs. to the barrel. The ale soon becomes fine, and is seldom racked for the home market.[1]

Among the multitude of recipes for domestic brewing, on a small scale, one of the best (we speak from the experience of several years) is that given by Mr. Donovan, in the work already quoted. The great objection to domestic brewing is often the expense of the apparatus; but this writer shows how cheaply this may be procured. A common porter-barrel forms the mash-tun, for which purpose one end is to be taken out, and converted into a false bottom, by letting it rest on a hoop nailed round the lower part of the barrel. This false bottom is to be perforated with a vast number of gimlet holes, and a cock or spigot of wood is to be fixed in one of the staves, between the real and the false bottom. Another porter-barrel, with one end taken out, will serve both as underback and fermenting-tun, and it may be placed beneath the cock of the mash-tun, so as to receive the wort when it is drawn off. A tin-plate boiler, furnished with a cock at the bottom, for placing over a common fire-grate, is recommended for heating the mash liquors, but we prefer to use the laundry copper, which is provided in every house. A brewing thermometer may be used, but can be dispensed with, as the proper heats can be determined by the admixture of cold and boiling water.

15 gallons of boiling water are to be thrown into the mash-tun, and 5 of cold water (60°). The temperature of the mixture would be 174°, but for the cooling influence of the wooden vessel, which, however, should be well scalded immediately before. The mash-water will be about 170°. 2½ bushels of the best ground pale malt are to be quickly shaken in, while a second person continually stirs with a stick, and this mashing is to be continued for half an hour, the barrel being covered over all the time with a thick cloth, except in the small space where the stick is inserted. The tun should then be left quiet for an hour, after which the cock may be opened a little. The first flow of wort should be received into a wooden bowl: if not clear, it should be gently poured back into the mash-tun; but as soon as it begins to flow clear, the cock may be opened to the full. The malt will have soaked up the greater portion of the water, but the few gallons which flow off ought to be a full, rich, clear wort. Just when the last portions have run off, 20 gallons of water, not quite boiling, are to be lightly let over the residual grains. The wort retained by the malt will thus be washed down, and the whole quantity now in the underback will amount to 23 gallons. This is to be baled into the copper, and boiled for 20 minutes with 3¼lbs of the best mild hops, after which it is to be passed through a large sieve into the fermenting-tun; and when it has cooled nearly to blood-heat (98°), about a quart of good yeast is to be mixed in, and the fermentation is to be continued until completed. In cold weather the tun while working must be kept near the fire, as on this small scale the wort does not maintain the temperature adapted for working. When the fermentation shows a decided tendency to go down, the liquor is to be racked off, and put into a cask, and closely bunged up. The ale will measure 20 gallons, and will be ready for use in about a fortnight.

BEET, BETA. This important, but common, plant belongs to the natural order Chenopodiaceæ, which also includes Spinach, Orache, Mercury, Goose-foot, &c. Beet, more commonly known by its German name of *mangold wurzel*, is now famous as affording a new source of sugar, capable of being produced in northern countries. Common Beet (*Beta vulgaris*) has been extensively and successfully cultivated for this manufacture, which was commenced in the time of Napoleon, to gratify his earnest desire of rendering France independent of England, and was carried on under his constant notice and patronage, so that it is said he proudly exhibited the first specimen of beet-root sugar as one of his greatest treasures. The mode of cultivation recommended by French naturalists, and found successful in rearing the plants, was as follows:—A low situation should be chosen, in which extremes of drought and moisture do not occur. The soil (which should be a rich loam in which wheat has been grown) must have three good ploughings, and immediately after the third, which should take place at the end of April or beginning of May, it must be brought smooth by the harrow, and laid out for planting. This is done in France by means of a rake, whose teeth are from 9 to 12 inches apart, and are therefore fitted to make lines along the surface, showing the distance each row of plants is to be from the other. The rake is afterwards drawn in transverse lines across these, and the ground divided into squares, measured by the distance of the rake's teeth. Into each intersecting point of these lines, one capsule containing several seeds is inserted to the depth of an inch. When the young plants begin to spring up, and six or eight leaves are formed, the ground should be weeded, and if necessary, the plants thinned. After this the crop advances so rapidly that the outspreading leaves soon cover the ground, and thus completely prevent the growth of any more weeds. There is therefore no more trouble with the ground till the time of gathering, an important circumstance for the cultivator, who is then busy with his corn harvest. The beet does not attain its full perfection till the month of October.

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[1] Roberts, "Treatise on Brewing," [illegible]

The best seed is that obtained from beet which has not been transplanted, and which has produced thin spindle-formed roots. Among the varieties which produce this kind of root, one has a pale red rind, and is internally quite white. This is a valuable variety to the manufacturer, yielding much sugar and an agreeably sweet syrup; others have a deeper red rind, and reddish circles or stripes within. These have a less agreeable syrup, retaining a taste of the root, which cannot be removed without expensive chemical processes. Other varieties are white on the outside and yellow within. These yield much crystallizable sugar, but are not fit for moist or raw sugar on account of the disagreeable taste of the syrup.

Various experiments have been tried with beet, to ascertain the effect of light on the development of the saccharine principle, and it seems to be fully proved that as in the case of asparagus, endive, &c., the part protected from the light becomes sweet, while the other parts remain bitter, so with beet-root, the saccharine principle is greatest in those roots which are the most effectually protected from the light. Thus the natural growth of these plants, by which the leaves form a thick and umbrageous covering to the whole of the ground, should by no means be interfered with, and the practice occasionally followed of removing all the large leaves, is one which must necessarily deprive the root of a portion of its most valuable properties. The only leaves which it is safe to remove are those which have begun to droop or decay; but to pluck the large succulent leaves, however convenient they may be as food for cattle, is very unwise in those who grow beet for making sugar. For a description of the process by which the sugar is obtained from beet-root, see SUGAR.

BELL. See CASTING.

BELL-METAL. An alloy of copper and tin. [See BRONZE. CASTING.]

BELLOWS and BLOWING MACHINES. The common bellows is a very ancient instrument for assisting the combustion of a fire, by injecting into it a larger portion of air than would be supplied without such aid. The first form of this machine resembles that of the lungs, and was doubtless suggested by the common practice of blowing the fire by means of the mouth. It consists of two flat boards of an oval or triangular shape, each furnished with a projecting handle, and between the boards two or more hoops are bent to suit their figure. To the edges of the boards is nailed a piece of leather, broad in the middle, so as partly to enfold the hoops, and narrow at the two ends, thus forming a sort of enclosed chamber, capable of being enlarged or contracted by raising the upper board while the lower one remains stationary. To the lower board is fastened a metal pipe, and a hole is also made in the centre of this board, which is covered on the inside with a leathern flap or valve opening inwards. On raising the upper board the enclosed air is of course rarefied, and air from without rushes in by lifting up the valve. Then on pressing down the top board, the air is compressed, and driven forward along the pipe with a velocity depending on the amount of force with which the two boards are pressed together. The blast is not continuous, but in puffs,[1] an interval of time being required for the air to enter the bellows through the valve, the blowing interval being to the filling interval as the areas of the apertures. In the oldest smelting houses this irregular blast was remedied by employing two bellows which blew alternately, the one blowing while the other was filling. To supersede the necessity of frequent repairs, they were made entirely of wood, except the pipe or twyere. This invention is ascribed by Beckmann to one Lewis Pfannenschmid, of Thuringia, who settled at Ostfeld, near Goslar, in 1621, where he excited the jealousy of the bellows-makers of the place by the superiority of his machines. It is stated, however, that bellows entirely of wood for smelting houses and for organs, were constructed at Nuremberg as early as 1550. Beckmann describes these machines in the following terms:—"The whole machine consists of two boxes placed the one upon the other, the uppermost of which can be moved up and down upon the lower one, in the same manner as the lid of a snuff box which has a hinge moves up and down when it is opened or shut, but the sides of the uppermost box are so broad as to contain the lowermost one between them, when it is raised to its utmost extent. Both boxes are bound together at the smallest end where the pipe is, by a strong iron bolt. It may be readily comprehended, that when both boxes fit each other exactly, and the upper one is raised over the under one, which is in a state of rest, the space contained by both will be increased; and consequently more air will rush in through the valve in the bottom of the lower one: and when the upper box is again forced down, this air will be expelled through the pipe. The only difficulty is to prevent the air which forces its way in from escaping anywhere else than through the pipe; for it is not to be expected that the boxes will fit each other so closely as to prevent entirely the air from making its way between them. This difficulty, however, is obviated by the following simple and ingenious method:—On the inner sides of the uppermost box

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(1) A very convenient form of domestic bellows was introduced a few years ago, producing a constant blast. A vaned wheel was enclosed in a tinned iron box communicating with a tube. The supply of air was obtained by means of holes in the side of the vessel, so that by turning a small multiplying wheel at the side the vane was set spinning, and, drawing the air in, projected it out along the tube.

there are placed movable slips of wood, which by means of metal springs are pressed to the sides of the other box, and fill up the space between them. As these long slips of wood might not be sufficiently pliable to suffer themselves to be pressed close enough, and as, though planed perfectly straight at first, they would in time become warped in various directions, incisions are made in them across through their whole length, at the distance of from 15 to 18 inches from each other, so as to leave only a small space in their thickness, by which means they acquire sufficient pliability to be everywhere pressed close enough to the sides." These bellows are made of clean fir-wood without knots. They are represented in Fig. 117, in which A E B F is the upper chest. E F the line of hinges, H the handle, and P the blast pipe, which is sometimes furnished with a valve opening outwards, to prevent the burning coals from being sucked into the bellows when the upper box is drawn up. The lower box, with one of the valves V, is shown separately in Fig. 118. The slips of wood at the sides are apt to become damaged, but they can be easily repaired, and every 3 or 4 months the outer sides of the inner box and the bolt which keeps the boxes together must be smeared with oil.

Fig. 117.

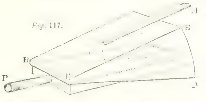


Fig. 118.

These bellows are of very large size; they are 16 feet long by 5 feet, and the circular end is also 5 feet. The rise is 3 or 3½ feet, expelling at each stroke about 90 cubic feet of air, and making eight strokes per minute.

The great objection to bellows of this kind, is the want of a continuous blast. This was first remedied by the addition to the single bellows first described, of a third board of the same shape as the other two, and connected with the lower board by means of a piece of leather, thus making two exactly similar cavities or chambers, separated by the lower board of the single bellows, which now becomes the middle board of the double bellows. Each of these two boards is furnished with a valve, and the blast-pipe is connected with the upper part of the middle board. The lower board is held down by a weight, and a weight is also placed on the top board, by which means the air is forced out of the upper cavity through the pipe. In blowing, the middle board is raised, by which means air rushes into the lower cavity, and in its descent forces air into the upper cavity, the valves preventing its return, and the weight on the upper board forces it out through the pipe in a continuous blast. Thus it will be seen, that the ascent of the middle board fills the lower cavity while the descent fills the upper cavity, and the weight of the top board drives the air out in a blast; thus the irregular puffing action of the single bellows is here confined to the lower board, which supplies air to the upper cavity. The blast, although continuous, is not, however, quite regular, for when the air is forced into the upper cavity, an excess of pressure is communicated to the air contained therein, but this is of no consequence in a smith's forge.

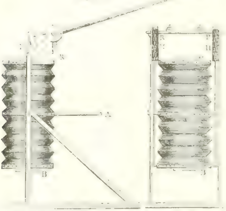
Fig. 119.

This construction will be understood by reference to the bellows in Halley's portable forge, Fig. 119, in which *a a* is a square frame of iron passing round the whole; *b b*, pillars supporting the platform or hearth for the forge fire; *d*, the bellows made fast by the middle flap to the frame *a*, and worked by the handle *e*, inserted in a socket at the top of the lever *f;* this lever and a corresponding arm on the opposite side, swinging upon pivots mounted on the sides of the frame *a*, and connected by a rod *g*, which passes across the machine under the bellows. By depressing the handle *e*, the levers *f* lift the rods and the bottom flap of the bellows, and on lowering the handle this flap falls by its own weight, thus producing the blast for working the forge. The flaps are covered with iron plates to increase the effect, and are nearly square to afford greater space. The collapsing of the upper flap forces the blast up the pipe *h* to the fire. To make this furnace portable, the parts are taken asunder, and the bellows and frame are placed on the hearth *c*, the pipe *h* and the legs *b* are packed on the top and sides of the bellows, and the whole is shut up in a box, formed by the hearth of the forge with its side plates; the cover is then turned down by its hinge-joints upon the box, and secured by a hasp and padlock.

Fig. 120.

The smith's bellows is worked by means of a rocker, with a string or chain fastened to it. By drawing down the handle of the rocker the movable board rises. The smith's bellows is sometimes made circular, the boards being in a horizontal position, parallel to each other, as in Fig. 121, in which A is the blast-pipe, B the movable lower board, C the fixed board with the pipe inserted, D the upper moveable board loaded with a weight. Motion is given to the lower board by means of a lever L, and a chain H working on a roller R. The weight required to produce a certain force of blast is easily determined, for if the diameter of the bellows be 1 foot the area

Fig. 121.



will be 113 square inches, and the upper board would require a weight of [illegible] lbs. [illegible] equivalent to a pressure of [illegible] on the square inch, or a velocity of 207 feet per second, a blast well adapted to a smith's forge. The force of the blast may be varied by altering the diameter of the pipe, [illegible] when a speedy continuance is [illegible]. In powerful forges, the boards are [illegible] by means of helical springs instead of weights.

In some of the native furnaces for smelting iron ore in Hindostan, two bellows [illegible] are used; a pipe projects from the bottom of each, and is

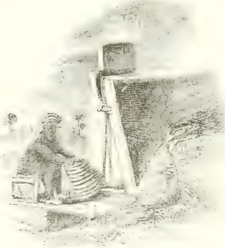
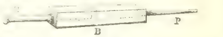


Fig. 122.—Indian Bellows.

united with the blast-pipe of the furnace. These bellows are placed on a plank laid across a trench in front of the furnace, and at the further end of the plank is seated a man, who by working the bellows alternately, one with the right, and the other with the left hand, produces a continuous blast. In front of the furnace is an ingenious contrivance for preventing the twyere from rising when the bellows is drawn up. It consists of a bar, the bottom of which presses on the end of the twyere, while its tip hitches into a loop of iron placed between two lateral studs or staples. The dotted line shows the form of the hearth, and the direction of the flue.

A very simple form of bellows, perhaps the simplest, is that used by the Chinese smiths. It consists of a square pipe of wood, Fig. 123, with a square board B exactly fitting it, which is moved to

Fig. 123.



and fro by means of a handle H. At the further end is the blast-pipe P, and in each side is a valve (shown by the dotted line) opening inwards

A very ingenious and powerful blowing machine, founded on the principle of the Chinese bellows, was constructed some years ago by Mr. Vaughan, and is described in the Encyclopædia Britannica. It consists of two square boxes placed side by side. A piston, P P', Fig. 124, fitting each, is

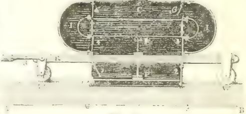
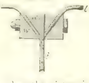


Fig. 124.

drawn backwards and forwards by means of the rod R, working horizontally on wheels W W, by means of the spear S, which communicates with the crank of a wheel at some distance off. The body of the piston is a cast-iron plate with a socket in the middle to receive the rod; the diameter of the piston is about $\frac{1}{4}$ of an inch less than that of the box, and it is made tight by the following ingenious arrangement. Two pieces of wood, W, are cut diagonally to receive pieces of leather, *l l*, between them, and both the leathers and the wood are firmly bolted to the plate of the piston *p*. The leathers extend about two inches beyond the wood, and their slight elasticity keeps them in contact with the metallic surface, so that when the piston is in motion the leather on one side claps close to the surface, rendering it air-tight, while the leather on the other side is loose.

Fig. 125.

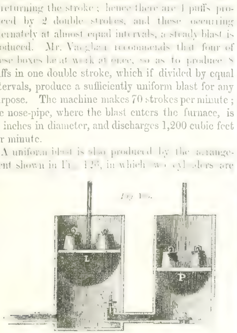


The projecting curved pipes, I I', communicate between the box where the piston works and the air-chest C. When the piston moves from A to B, the valves 1, 3 open, while 2, 4 remain shut. The air contained in the box is forced through the valve 6, into the chest C, and thence along the blast-pipe B P. In the return stroke, which is the whole length of the box, the valves 1, 3 are shut, while 2, 4 are open, and the air is forced through 5 and then along B P.

Two of these machines work at the same time by two cranks, so that one is in full blast while the other is returning the stroke; hence there are 4 puffs produced by 2 double strokes, and these occurring alternately at almost equal intervals, a steady blast is produced. Mr. Vaughan recommends that four of these boxes be at work at once, so as to produce 8 puffs in one double stroke, which if divided by equal intervals, produce a sufficiently uniform blast for any purpose. The machine makes 70 strokes per minute; the nose-pipe, where the blast enters the furnace, is 2½ inches in diameter, and discharges 1,200 cubic feet per minute.

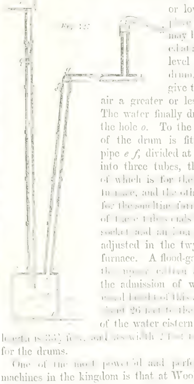
A uniform blast is also produced by the arrangement shown in Fig. 126, in which two cylinders are connected with each other and with the discharge pipe. P is the working piston, which is worked by a rod connected by double chains with the arched head of a working beam moving round a gudgeon. By the descent of this piston, the air is compressed and forced through the valve V, while the loaded piston L is raised to its highest point. The piston P now ascends, and its cylinder is filled with air through the valve V′, during which time the loaded piston gradually descends. The valve V is closed by the pressure and the air is forced out through the discharge pipe *d*. Before all the air in the cylinder L is discharged, it receives a fresh supply by the descent of P, and thus while the engine is in motion the blast is rendered continuous.

Fig. 126.



The *trompe*, or water blowing engine, Fig. 127, is an ingenious and economical method of obtaining a blast. It is used in Savoy, Carinthia, and in America. It is formed of two pipes or funnels, one of which is at *b*, set upright, and terminating above in a cistern of water *a*, and below is a tub or drum *c*. The conical part *p*, just below the cistern, is called the *étranguillon*, and prevents the water discharged into the trompe from filling the pipe in falling, but divides it into many streamlets. Below this narrow part a number of holes *q q* are perforated obliquely, through which air is admitted and carried by the water in its descent. The air parts with the water by dashing upon a cast-iron slab *d* within the drum. At the bottom of the drum is an aperture for the escape of the water, but to prevent the air from escaping with it, the water as it issues is received into a chest *l m n e*, divided into two parts by a vertical slide-plate between *m n*. By raising or lowering this plate the water may be maintained at any required level within the drum, so as to give the included air a greater or less pressure. The water finally drains off by the hole *o*. To the upper part of the drum is fitted the air pipe *e f*, divided at the point *f* into three tubes, the principal of which is for the cupellation furnace, and the other two at *g* for the smelting furnaces. Each of these tubes ends in a leather socket and an iron nose-pipe *h* adjusted in the twyere of the furnace. A flood-gate fitted in the upper cistern *a* regulates the admission of water. The usual height of this apparatus is about 26 feet to the upper level of the water cistern. Its total length is 35½ feet, and its width 2 feet to give room for the drums.

Fig. 127.



One of the most powerful and perfect blowing machines in the kingdom is that at Woolwich dockyard, which is used for supplying air to forty forge fires, and which are used for forging anchors, iron knees, and other heavy pieces of smithery. It consists of three blowing cylinders, Fig. 128, which are 5 feet 5 inches in length, of which 2 feet 4 inches is above the floor. The interior diameter of each cylinder is 4 feet 8 inches, which is

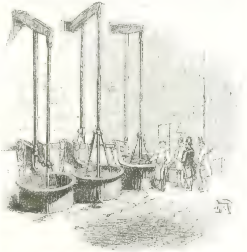


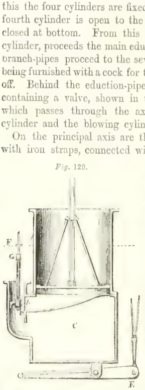
Fig. 128. THE WOOLWICH BLOWING ENGINE.

also the length of the stroke. Twenty strokes per minute are made in each of the three cylinders, corresponding to an expulsion of nearly 5,000 cubic feet of air per minute. The fourth cylinder is used to regulate the pressure, as will be explained presently.

The piston-rods are worked so that while one is at the highest, another is half-way down or up, and the third is quite down. A large iron wind-chest, 22 feet 5 inches long, is situated in the cellar below: on this the four cylinders are fixed. The bottom of the fourth cylinder is open to the chest; the others are closed at bottom. From this chest, under the third cylinder, proceeds the main eduction-pipe, from which branch-pipes proceed to the several forges, each pipe being furnished with a cock for turning the blast on or off. Behind the eduction-pipe is a short cylinder, containing a valve, shown in the section, Fig. 129, which passes through the axis both of the valve cylinder and the blowing cylinder.

On the principal axis are three eccentric wheels, with iron straps, connected with a lever under the wind-chest, and these wheels are so arranged in respect to the corresponding crank that when the piston of any cylinder is either above or below, the lever is horizontal, and the valve *v* exactly closes the hole *h*. When the piston in this figure begins to ascend, the end E of the lever continues to ascend also, and the other end F descends, and being connected with the valve-rod at G, this also descends, and opens a communication between the interior of the cylinder and the external air, which rushes in with a fresh supply. This valve continues to descend until the piston is half-way up; it then begins to ascend until the piston is at the highest point, when the valve has the position shown in the figure. The piston now descends, but the valve-rod continues to ascend, and opens a communication between the cylinder and the wind-chest, into which the air is forced by the piston. When the piston is half-way down, the valve-rod has reached the highest point, and then continues to descend with the piston until the latter is down, when the hole *h* is again covered with the valve. In this way the three cylinders are successively opened to the atmosphere and to the wind-chest, and a constant influx of air is produced. To preserve a steady action in the valve-rods, they are made to pass through guards level with the floor F. The fourth cylinder has no bottom, but is open to the wind-chest, and its piston, which weighs 700 lbs., serves only to regulate the pressure, which amounts to about ¼ lb. on the square inch. When the pressure exceeds this, the piston rises, and opens a safety-valve at the back of the cylinder. The form of the bottom of the cylinder in the section belongs only to that part of the cylinder: the other part is perfectly flat, its purpose being to open a communication with the valve-cylinder. [See APPENDIX.]

Fig. 129.

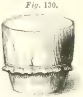


BENZOIC ACID. When bitter almonds are subjected to great pressure, a fixed oil is obtained. By distilling with water the almond-paste which remains, a volatile oil is obtained, which is prepared in large quantities, chiefly for the use of the perfumer. This oil does not pre-exist in the almonds, but appears to be formed by the action of water upon a peculiar crystallizable substance called *amygdaline*, aided by the presence of the pulpy albuminous matter of the seed. The crude oil has a yellow colour, and contains a quantity of hydrochloric acid, which is formed at the same time as the oil. By agitating it with a solution of protochloride of iron, containing an excess of hydrate of lime, and then distilling the whole, the essential oil is obtained in a purified form. It is freed from the water which passes over with it by means of fused chloride of calcium.

This oil is supposed to be the hydruret of a basic substance named *benzoyle*, from its relation to benzoic acid, containing $C_{14} H_5 O_2$. Pure hydruret of benzoyle, or bitter-almond oil ($C_{14} H_5 O_2 + H$), is a thin colourless fluid, of great refractive power, and of a peculiar and agreeable odour; its density is 1.043, and its boiling-point 356°. Its vapour is inflammable, and burns with a bright smoky flame. It is soluble in about 30 parts of water, but alcohol and ether dissolve it indefinitely. It absorbs oxygen rapidly from the air, and forms a mass of crystallized benzoic acid. It is doubtful whether the pure oil is poisonous but the crude product is highly so, and yet this is sold for flavouring puddings, custards, &c.

Benzoic acid, or oxide of benzoyle, BzO ($C_{14} H_5 O_2 + O$), is not usually obtained by the oxidation of bitter-almond oil. Several of the balsams, especially gum-benzoin, yield benzoic acid in abundance. By exposing this substance to a gentle heat in a subliming vessel, the benzoic acid is volatilized, and condensed in the upper part of the apparatus. The best contrivance for this purpose is a shallow iron pan, containing the substance to be sublimed, in a thin layer: a sheet of bibulous paper, pierced with a number of pin-holes, is stretched over the pan, and a cap of stout cartridge-paper, secured by a string or hoop, is drawn over the whole, as in Fig. 130. The pan is slowly heated on a sand-bath; the vapour of the acid condenses in the cap, and the crystals are prevented from falling back into the pan by the porous paper. The acid thus obtained is in the form of snow-white, light, feathery crystals, with a fragrant odour, which is due to the presence of a small quantity of volatile oil. A more abundant product may be obtained by mixing the powdered gum-benzoin with an equal weight of hydrate of lime, boiling the mixture with water, filtering, and evaporating, and then decomposing it with an excess

Fig. 130.



of hydrochloric acid. The benzoic acid crystallizes out on cooling, in thin plates, which may be drained upon a cloth filter, and dried in the air. By sublimation the acid may be obtained perfectly white. The crystals obtained in this way contain an equivalent of water, so that the formula for the hydrous acid is $C_{14} H_5 O_3 + HO$.

Benzoic acid is inodorous when cold, but has a faint smell when gently heated; it fuses just below 212°, and sublimes a little above that point: it boils at 462°, and emits a dense vapour, which is very irritating to the throat and eyes. It dissolves in about 200 parts of cold, and 25 of boiling water. It dissolves in about twice its weight of alcohol; it also dissolves in ether, and in fat and volatile oils. It combines with bases, and forms salts, which are called *benzoates*.

Benzoic acid is an ingredient in some kinds of perfumery, and in fumigating powders and pastiles. It was formerly used as an expectorant in asthma and dry cough. When taken internally, it is rejected from the system in the state of hippuric acid, which occurs in large quantity, in combination with potash or soda, in the urine of horses, cows, and other graminivorous animals. If the urine be slightly putrid, it yields benzoic instead of hippuric acid. Much of the cheap benzoic acid of commerce is prepared in this way, the perfume being superadded by sublimiug with a little gum-benzoin. Benzoic acid is a principal ingredient in *friars'-balsam,* useful for stimulating languid wounds, but mischievous when applied to recent wounds. A cosmetic, under the name of *virgin's-milk,* is prepared by mixing two drachms of the alcoholic solution of benzoin with a pint of rose-water.

The other benzoyle compounds, such as the chloride, bromide, iodide, and sulphuret of benzoyle, possess great chemical interest, but are not of importance in a manufacturing point of view.

BILE. A secretion separated from venous blood by the largest internal organ of the body, the liver. It was regarded by the old chemists as a saponaceous compound, in which an organic acid was combined with soda. Modern chemists have re-adopted this view, regarding bile as a *soda-soap,* and, as such, the bile of the ox, or *ox-gall,* as it is called, is used in the arts, by painters in water-colours, scourers of clothes, and many others; but, from its green colour, it requires for many purposes to be clarified. This is done by allowing the fresh gall to settle for a day in a basin; the liquor is then poured off from the sediment into an evaporating-dish, and exposed to a boiling heat in a water-bath until it is somewhat thick. It is then spread upon a dish, and dried before the fire, in which state it may be kept for years in jelly-pots covered with paper. When required for use, a piece of the size of a pea may be dissolved in a table-spoonful of water. The gall may be made perfectly colourless by the following process: A pint of gall is to be boiled and skimmed, and an ounce of alum, in fine powder, or an ounce of common salt, added; the mixture to be kept on the fire until the alum is dissolved. The mixture, when cool, is to be poured into a bottle, and loosely corked. In about three months it deposits a thick sediment, and becomes clearer. The clearer portion of the gall prepared with alum is then to be mixed with the clear portion of the gall prepared with salt, when the colouring matter will be coagulated and precipitated, leaving the ox-gall perfectly colourless. It may, if necessary, be further purified by passing it through filtering-paper. This gall becomes purer by keeping, and never loses its good qualities, nor contracts a disagreeable smell.

Prepared gall combines with colouring matters and pigments, and gives them solidity either by being mixed with or passed over them upon paper. It adds to the brilliancy of ultramarine, carmine, green, and most delicate colours, and makes them spread more evenly upon paper, ivory, &c. Mixed with gum arabic, it thickens the colours without giving a glistening appearance; it prevents the gum from craking, and fixes the colours so well, that others may be applied over them without running into them. Mixed with lamp-black and gum, it forms a good imitation of China ink. A coat of ox-gall upon black-lead or crayon drawings prevents the lines from being effaced, and such drawings may be safely coloured by first mixing the colours with ox-gall. Miniature painters use it for removing the unctuous matter from the surface of ivory, and when ground with the colours it enables them to be spread easily and renders them fast. It is also useful for transparencies, by passing it first over the varnished or oiled paper and allowing it to dry. The colour is mixed with the gall and then applied, and cannot afterwards be removed.

It takes out spots of grease and oil, and is useful to the laundress in washing dresses, the colours of which would run or be removed by the ordinary process of washing. A small portion dropped into ink renders it fluid.

BINNACLE, or BITTACLE (from the French, *habitacle,* a small habitation). The box in which the compass is placed for steering a ship. The form is not of much importance by day, provided the man at the helm can get a good view of the compass-card; but at night it is of great consequence to throw the strong light of a lamp on the card, to preserve the lamp from the action of wind and weather, and to prevent its light from being seen out of the ship.

Sir Home Popham's binnacle is in general use in the navy. It consists of a square box about 2 feet high and 18 inches in the side, with a top in the form of the frustum of a square pyramid. The four sides are glazed with plate-glass, and the compass-card, which is about level with the upper part of the square box, is distinctly seen. By night thin copper screens shut up those sides which are not necessary for the steersman's purpose, and the inner surfaces of these screens assist in reflecting the light of the lamp strongly upon the card. The lamp is attached to one of these screens, a hole being cut in it to admit the necessary light. To prevent the fracture of the glass surfaces, the four edges of the frustum are defended by a strong wooden frame with projecting edges, and at the top by a flat piece of wood also projecting considerably beyond the glass.

A good arrangement of a ship's binnacle is that by Mr. Grant Preston, of Wapping, described in the Transactions of the Society of Arts. The defects of the ordinary binnacle and compass-box are first pointed out by him. The compass-box is generally of wood, and square, containing within it a circular brass box suspended on gimbals; within this is the compass-card, the points of which are read against a mark within the brass box, called the *lubber's point* or *mark*. A line drawn from this to the centre of the compass-card should be exactly parallel to the line of the ship's keel, or her course by the compass will not be correct. The mode of fitting the compass-box into the binnacle is by driving wedges all round to make it fast, but nothing is done to make it truly parallel with the ship's keel. The binnacle is sometimes made with three divisions instead of two, in which case a compass is placed in the two outer divisions, and the light between them; but this method is objectionable, because the needles are liable to act upon each other. The light is often thrown upon the compass-card very imperfectly, and may also be seen at a distance from the ship, which is an objection.

Mr. Preston's binnacle has a cylindrical top for enclosing the lamp in a case, so that it can be lighted below in bad weather. The light is powerful and steady, and is thrown vertically upon the compass-card, and the expenditure of oil is small. No direct light is seen, to dazzle the eye of the steersman, nor is any light shown which can be seen by the enemy at sea.

Fig. 131 represents this binnacle as it stands upon the deck of a vessel, opposite to the steering-wheel. Fig. 132 is a section of the box containing the lamp and reflector. A A is a square box closed by a door in front, but omitted in the figure in order to show the interior. This box is fixed down, with the two sides parallel with the ship's keel. B is a shelf in the box, to support a board C, which exactly fits the box, but has its angles taken off, to allow it to slide in and out freely: C has a stem *a*, of brass wire, standing up from the centre, and terminating in a sharp point, on which the compass-card is freely suspended to turn round; being then included within a circular opening made through the top of the box, and its divisions reading against the *lubber's point*, drawn on a piece of white paper, and seen plainly in the figure. The opening in the top of the box is surrounded by an octagonal lantern, which has glass panes in all its sides, which are closed at night by sliding shutters *a a*. The compass is seen through the glass *b*, placed at a proper inclination to command the view of the card. The lamp is situated in a circular box, fitted with a ring F at the top of the lantern-frame, and as a dome G, with a chimney *d* to carry off the smoke. The section, Fig. 132, will explain the interior parts. H H are the sides of the cylindrical box which fits into the ring *f*, Fig. 133. *c c f f* are the sections of two brass circles or gimbals, shown separately in Fig. 133. The external one has two projecting points, which are received in pieces of copper, soldered to the inside of the box; the internal ring has similar pivots, but these are received into holes in the outer ring, the direction of the two lines of pivots being at right angles to each other, so that the interior ring, and all that it supports, has universal motion, and, if properly balanced, will preserve its horizontal position in any inclination of the box. I K is a brass box, shown separately, fitting the ring *f*, and in the bottom is a large plano-convex lens, K K, which concentrates the light of the lamp, and throws it down upon the card. The lamp L is just within the box: it consists of a deep hollow hoop of copper, L, Fig. 133, for containing the oil, which is poured in by two tubes, *g h*. The wick *i* is contained in a narrow spout proceeding from the interior to the centre of the hoop, and the flame projects over the end of the spout. The conical chimney M includes a reflector of tinned iron, well polished, which reflects

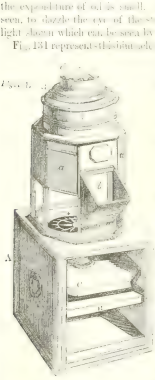
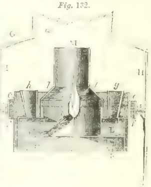


Fig. 131.

Fig. 132.



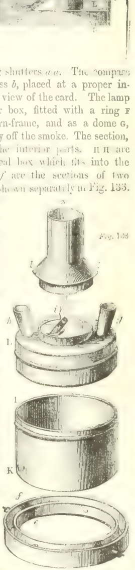


Fig. 133.

the light downwards. By these means the card is well illuminated, and if the shutters *a a* be put down, no light escapes except at the aperture *b*, and this directs the light upwards in a direction in which it will not fall upon any part of the ship.

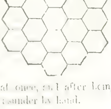
BIRD-LIME. This substance is now in great part imported into England from Turkey, but was formerly manufactured here to a considerable extent, and exported to India for the purpose of destroying insects. It is a green substance, viscid and tenacious, made from the bark of various shrubs, but chiefly from that of the common holly. It may also be made from mistletoe and other parasites. It contains a resin (which has been called *viscine*), mucilage, colouring and extractive matter, and a little free acid. The middle bark of the holly contains a large amount of viscid matter, and from this, and the bark stripped from the young shoots, the best birdlime is made. The bark is boiled six or eight hours in water, until tender; it is then drained from the water, and laid in pits, for two or three weeks, to ferment, being occasionally moistened with water, if necessary. After this it is taken out, and reduced to a paste by pounding in mortars, then washed and kneaded, and packed in earthen vessels. After three or four days, during which it ferments and purifies itself, it is fit for use.

BISCUIT (Latin, *bis coctus*, twice baked). An unfermented bread, which, if properly prepared, can be kept for a great length of time, and hence its use as a common form of bread at sea. At present the ships of the Royal Navy are supplied with biscuits made by machinery, before the introduction of which they were made by hand in the following manner. A gang of five men were employed, who were severally named, the *furner*, the *mate*, the *driver*, the *breakman*, and the *idleman*. The driver made the dough, by mixing the flour and water together in a trough with his naked arms, until, by a laborious operation, a proper consistency was obtained. The rough dough was then deposited on a break, or wooden platform, to be worked by the breakman, who kneaded it by riding or jumping upon it by means of a breakstaff. When sufficiently kneaded, it was taken to a strong table, called the moulding-board, where it was first cut into slips, then divided into lumps of the size of the biscuit, then moulded by hand into the circular shape, and lastly *docked*, or pierced full of holes, by means of a *docker*, the whole of the gang assisting in this operation. The oven being properly heated, the biscuits were pitched in by the joint labours of the furner, the mate, and the idleman. The gang thus produced 100 lbs. weight of biscuit in 36 minutes, including 15 minutes, the time allowed for baking. Hence the nine ovens in the Royal Clarence Victualling Yard at Gosport required the labour of 45 men to keep them in full operation, and the produce was about 14 cwt. of biscuit per hour, at a cost for labour and utensils of 19*d*. per cwt.

The good quality of biscuit chiefly depends on the thorough kneading of the dough, and its subsequent division into portions of equal size and thickness. If the meal be not equally mixed with the water, some portions of the biscuit will be wetter than others, and will require more baking than the dry parts: these will be overbaked or burnt up, or the moist parts will remain unbaked; the biscuit thus becomes *hard* or *flinty*. So also if the biscuits are of unequal thickness, if the thin ones are not overbaked, the thicker must be underbaked; and the thin parts of a badly moulded biscuit will *perish* from the action of the fire, while its thick part is converted into *flint*.

About the year 1833 this method was superseded by machinery contrived for the purpose by Mr. Grant, of Gosport. In the first process, the meal is conveyed into a cylinder 4½ feet long, 3 feet 2 inches in diameter, and the water is let in from a cistern at the back of the cylinder, regulated by a gauge to the exact quantity required for mixing the meal. Through the centre of the cylinder is fitted a shaft armed with knives, and working horizontally. The shaft being set in motion, the knives revolve through the meal and water. During the first half-minute the meal and water do not appear to unite; but after this the dough begins to assume a consistency, and in two minutes 5 cwt. of well mixed dough is produced. The cylinder is formed so that its lower half is easily separated by means of a wheel and pinion from the upper sides, thereby forming a trough containing the dough, from which it is removed, and placed under the breaking-rollers to be kneaded. These rollers, two in number, weigh 1,500 pounds each, and are propelled from off a two-throw crank-shaft by means of connecting rods and pendulums; they pass backwards and forwards over the dough during five minutes, when the 5 cwt. of dough is brought into a solid, perfect, and equal consistency. From the breaking-rollers the dough is cut into pieces 18 inches square, and placed on boards 6 feet long by 3 feet wide, which are conveyed by means of a line of friction-rollers connected by an endless chain under a second set of rollers, to be rolled to the required thickness of the biscuit. The square of dough being thus pressed out, so as to cover the surface of the board, on which it is transferred under the cutting and stamping-plate, is at the same moment cut and stamped, or *docked*, into 42 hexagonal biscuits, which, being now complete, are at once conveyed to the oven on carriages constructed for the purpose. The hexagonal shape is preferred in order that there may be no waste, the sides of each biscuit by this contrivance fitting accurately into those of the adjoining biscuits, as seen in Fig. 134. Each biscuit is stamped with the broad arrow, the number of the oven, and also docked by the same movement which cuts it out of the piece of dough. The hexagonal cutters do not completely separate the biscuits, so that a whole sheet of them can be put into the oven at once, and after being withdrawn, they are broken asunder by hand.

Fig. 134.



The corn for the biscuits is prepared at the Government mills: it is a mixture of fine flour and middlings. [See BREAD.] The ovens are of wrought-iron, with an area of about 160 square feet. About 112 lbs. weight of biscuits is put into the oven at one time: this is called a *suit*, and is reduced to about 100 lbs. by the baking. The men engaged in this work wear clean check shirts, and white linen trousers, apron, and cap; and the most scrupulous attention to cleanliness is observed.

The bakehouse at Gosport was provided with one mixing-machine, two breaking-rollers, four sheet-rollers, and four stampers; and it was calculated that this machinery would require eight men and eight boys, to supply the nine ovens; that the produce per hour would be 10,000 biscuits, or one ton of bread, at a cost for labour and other incidental expenses of 5¼*d.* per cwt. It was found, however, in practice, that the machinery could easily supply eighteen ovens, should it ever be advisable to enlarge the bakehouse to that extent. With the exception of the men employed in heating and managing the ovens, no professional bakers are required, ordinary labourers and boys being fully competent to every other part of the work. This is a great advantage, since, in time of war, it has hitherto been found very difficult to supply the navy with biscuit, and the men employed as biscuit-bakers required very high wages. In the late war, double gangs of workmen were constantly employed; but the supply of biscuit was so inadequate that the Government was compelled to have recourse to contractors, who supplied bad biscuit at a high price. It has been calculated that the three bakehouses at Deptford, Gosport, and Plymouth, could, by working eight hours per day, produce annually 7,354 tons of biscuit. If this quantity had to be made by hand, the price paid for labour and utensils, at 19*d.* per cwt., would amount to 11,643*l.* The machinery manufactures at 5¼*d.* per cwt., including 10 per cent. for wear and tear, and all other expenses; so that this same quantity of biscuit would be produced for 3,217*l.*, showing a net saving of 8,426*l.*[1]

The term *biscuit* is also applied to porcelain, when baked and not glazed. [See POTTERY and PORCELAIN.]

BISMUTH. A metal of no great importance in the arts. It was first distinguished from lead by Agricola, in the 16th century. It occurs native, and also in combination with oxygen, with arsenic and sulphur. It is found in very limited quantities in Cornwall, Germany, France, and Sweden. In the smelting works of the Saxon Erzegebirge, at Schneeberg, the metal is separated from its gangue by a very simple process. The ore is enclosed in tubes of iron plate, (Fig. 135), placed in an inclined position. The mineral is introduced by the opening at P, which is then shut. The other extremity is closed by a plate with a small aperture near the lower edge, through which the metal flows out as it is melted by the action of the heat. It is received into clay pots *c* on the outside, which are kept hot by a fire beneath them. From these pots the metal is ladled into moulds. In this state it is always contaminated by sulphur and arsenic, which, however, can be separated by fusing the metal with $\frac{1}{10}$th of its weight of nitre.

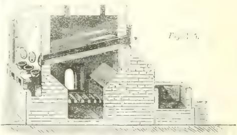


Fig. 135.

Bismuth (Bi 210) is a brittle white metal, with a slight red tint, which is very evident in holding a specimen by the side of a lump of antimony or zinc. Its specific gravity is 9.799. It fuses at 507°, or according to another authority 513°, and always crystallizes in cooling. It expands at the moment when it solidifies, so that it is lighter in the solid than in the liquid state. Good crystals may be obtained by carefully melting the purified metal, and then pouring it into a heated mould, and allowing it to cool very slowly and quietly. When a solid crust has formed on the surface, it is pierced in two opposite places near the edge, and the liquid metal is poured out at one hole, while the air enters at the other. The mould is then suffered to cool, and on removing the crust the cavity will be found lined with beautiful cubical crystals (Fig. 136), highly iridescent from the formation of a thin pellicle of oxide on the surface, at the moment when the hot metal comes in contact with the air. Bismuth transmits heat more slowly than most other metals, probably on account of its highly crystalline texture. It is volatile at a high temperature, and may be distilled in close vessels, but with difficulty. A cast bar of bismuth $\frac{1}{10}$th inch in diameter supports a weight of 48 lbs.

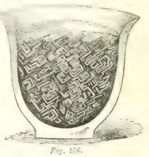


Fig. 136.

There are two principal oxides of bismuth, a teroxide and an acid oxide. There is also a compound oxide. The teroxide may be obtained by fusing the precipitate of subnitrate thrown down by water. This subnitrate, also called *pearl-white*, is used by some ladies as a cosmetic. It is more usefully employed as a flux for certain enamels, increasing their fusibility without imparting colour. It is hence used as a vehicle for the colours of other metallic oxides. When well washed it is employed in gilding processes, an addition of $\frac{1}{15}$th being made to the gold. It is also used in medicine.

Some of the alloys of bismuth were noticed under ALLOY. In this article it was stated that

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(1) Nautical Magazine, vol. i. New Series. 1857.

safety plugs of fusible metal formed of lead, tin, and bismuth have been used in steam boilers to provide against explosion. It was supposed that if the temperature of the steam should rise above a certain point, and the safety valve not be in a condition to allow of its escape, the plug would fuse, and afford a vent. It has been found, however, that when this alloy is exposed during a long period to a temperature near its fusing point, it undergoes a sort of *eliquation*, [See ASSAYING,] by which a more fusible alloy is melted out, and that which remains is much less fusible than the original alloy. In some explosions of boilers, the safety plugs have for this reason been found entire. Hence this mode of protecting boilers has been abandoned. [See ALLOY, App.]

Fusible metal has been successfully employed for making casts of anatomical preparations, and other similar purposes. Professor Brande says:—"It may be employed for taking casts from medals, and even from the surface of wood and embossed paper. Some beautiful casts have also been made in this metal of the internal ear, showing the complexities of its bony cavities." Cake moulds for the manufacturers of toilet soaps are also made of this metal.

BITTERN. The mother-liquor or uncrystallizable residuary solution of SALT WORKS, so called on account of its excessively bitter taste. Its principal ingredients are chloride of magnesium and sulphate of magnesia or EPSOM SALTS. [See SODIUM.]

BITUMEN, see ASPHALTUM.

BLACK-LEAD. PLUMBAGO. GRAPHITE. A mineral substance occurring in veins, and in kidney-shaped lumps, in gneiss, mica slate, and their subordinate rocks; also in transition slate, as in the valuable mine at Borrowdale, in the heart of the lake district of Cumberland. Black-lead has probably received its name from its colour, which is of a leaden or slaty grey, passing into iron black, but there is not a particle of lead in its composition. According to Vanuxen, the pure and impure varieties from Borrowdale contain:—

	Pure.	Impure
Carbon	88.37	61.27
Water	1.23	5.33
Silica	5.10	10.10
Alumina	1.00	3.20
Oxides of iron and manganese	3.60	20.00
	99.30	99.90

The ashes of plumbago are found to contain titanic acid, and "it seems probable," says Brande, "that in plumbago the oxide of iron is in combination with titanic acid and silica, and not with the carbon, so as to constitute a carburet of iron." Some specimens, as those from Barreros in Brazil, scarcely contain a trace of iron.

Black-lead has been found among the coal-strata, as at Cumnock in Ayrshire; it has also been found in greater or less purity, and occasionally worked in many other parts of the world, especially in the United States of America; but the English mine at Borrowdale has long maintained the pre-eminence, so that the "*crayons d'Angleterre*" are in great esteem throughout the continent. The Borrowdale mine was discovered in the reign of Elizabeth, and soon became celebrated for its valuable contents. The work-people engaged in it, and those from neighbouring mines, were not proof against the temptations to plunder. The latter would even cut their way through from their own mines, and carry off quantities of the black-lead. On one occasion a party of miners overcame the guard placed at the entrance, and kept possession of the whole place for several days. These depredations were resisted with difficulty, and were not put a stop to until many persons in the vicinity of the mines had become enriched thereby. At length an act of parliament was obtained, inflicting severe penalties on depredators, and this, with improved means of defence, has proved an efficient protection.

The mine is situated about half way up the side of a mountain called Seatoller Fell, in Cumberland, eight miles south of Keswick, and which rises to the height of 2,000 feet. From the entrance to the mine a horizontal cavity is excavated to the extent of several hundred feet into the body of the mountain, having a railway laid down for the transit of the ore. The entrance is protected by a substantial building, in which is a room for assorting and dressing the ore, which process is performed under strict surveillance, and with the threatening aspect of fire-arms. There is also a room called the dressing-room, in which the workpeople change their garments previous to entering the mine, and again after six hours' work, on leaving. In this room is a trap door which forms the miners' only means of entrance to the mountain. The plumbago is of a fine granular texture, and so pure that it requires very little labour to fit it for the market. When it has been assorted and dressed, it is packed in strong casks holding about a hundredweight each, and is thus forwarded to the proprietors in London. In former times this mine was only opened once in seven years, but owing to the increased demand for plumbago, it is now opened every summer for about six weeks, and during that short period as much as 30,000*l*. or 40,000*l*. worth of mineral is sometimes obtained. The closing of the mine is accompanied with laborious precautions for insuring its safety. The earth and rubbish previously excavated are wheeled back again to the opening of the mine, and heaped up there to the amount of some hundred cart-loads. This forms a dam to a rill of water which flows through the mine, and which being thus deprived of the means of outlet, rises to a considerable height, floods the mine, and affords the best protection against robbery.

This important mine is shared between a few individuals, and the product fetches from 35*s*. to 45*s* per lb. in the market. The market for black-lead is held monthly in London, at Essex Street, Strand. Specimens of the different qualities 3 or 4 inches long are exhibited to the seven or eight individuals who are the sole purchasers; and after being examined with a sharp instrument to ascertain the hardness, the choice is made, and the order given, the first choice being, however, accompanied with a higher price than the rest. But as there is no addition made to the quantity of black-lead during the year, it comes to pass, that at succeeding markets the specimens which had been previously rejected are all chosen in turn, until the whole is disposed of.

There are several mines of plumbago in the United States of America, the most important being that at Sturbridge, Massachusetts. The plumbago thence obtained is in large masses, in veins, in gneiss, and is coarsely granular and foliated in texture. The quantity annually procured amounts to about 30 tons. At Taunton, Massachusetts, the Sturbridge plumbago is prepared by first pulverising it, and then, by machine pressure, condensing it into thin sheets. These sheets are then sawn up of the size required. This resembles the French method, by which graphite even of coarse qualities is made useful by being ground fine and calcined, but in this latter case it is mixed in a paste with very fine clay, and lamp-black is occasionally added.

The purity of the English mineral enables the manufacturer to apply it to use by simply sawing out slender parallelopipeds, from 1 to 2 inches long, from sound pieces of plumbago which have been previously calcined in close vessels at a bright red heat. These parallelopipeds, enclosed in cases of cedar, form the best black-lead pencils. But they may be also used alone, being protruded as they are wanted from slender tubes, by means of an iron wire and screw contained in the new form of pencil case adopted of late years, and called the ever-pointed pencil. The cedar cases are made by cutting the wood with a circular saw into four-sided strips of a proper length, and these are arranged so that the thickness of two of them may form a square, of which one piece is thicker than the other, and is grooved by a common plough plane to receive the lead. This is first dipped in glue, and then adjusted to the groove, portion after portion, till the whole of the groove is filled. The surface is then smoothed down level, and the other half of the cedar is glued on, thus making a square black-lead pencil. To make this round, it is passed through a hole in an iron or steel puppet of the exact size of the pencil, and forced along by the workman. On the other side of this hole is an apparatus consisting of two gauges, and a small plane iron, revolving round an open centre, and cutting the pencil into a cylindrical form as it passes along towards a circular hole which next receives the newly fashioned pencil, and further compresses and polishes it before it is finally withdrawn by the workman with a pair of wooden nippers. To prepare the cylindrical leads for ever-pointed pencils is a work of much delicacy. The black-lead, first cut into square prisms, is ingeniously and gradually brought into the required form, by passing it through three different sized circular holes cut in pieces of ruby; the first converts the square into an eight-sided prism; the second changes the eight-sided to a sixteen-sided prism; the third converts it into a cylindrical form, and is of the exact size. The rubies in this operation do not last many days, and steel it is said is worn out in a few hours, so that the ever-pointed pencils, if genuine, can never be very cheap. Yet thousands of pencils resembling these, but made of composition instead of pure lead, are sold at an exceedingly low price.

The first attempt at artificial pencils which led to any important results was that of a French gentleman, named Conté, whose process has been already alluded to. The admixture of pure clay in various proportions, not only with black-lead reduced to powder, but with different coloured earths, enabled him to produce various degrees of hardness and tint which were highly advantageous, and caused these pencils to become celebrated, and to yield to the inventor and his family a handsome fortune. The clay was first carefully washed and diffused in large tubs of river water, and allowed to settle two minutes, when the milky liquor was drawn off from near the surface into the second tub, which thus received only the finest particles. The sediment in this second tub is extremely soft and plastic, and when dried on linen filters, is fit for use. Meanwhile, the plumbago has been powdered in an iron mortar, and calcined in a crucible to nearly a white heat. It is then ready to be mixed with the clay in varying proportions, a fine hard pencil being produced by 2 parts clay to 1 part plumbago, a softer pencil by equal parts of each. The powders when mixed are triturated with water to a smooth paste, and ground with a muller on a porphyry slab till they are of the consistence of thin dough. This dough is pressed into grooves in a smooth board, (previously boiled in grease to prevent the clay sticking to it,) and another board screwed down upon it, so that the air can only act on the ends of the pencils in the grooves, which accordingly contract and become loose in the grooves. The mould is put into an oven at a moderate heat further to dry the pencils, which are then taken out and still further hardened by setting them upright in a crucible, having a luted cover, surrounding them with sand or charcoal powder, and placing them in a furnace, where they are baked more or less, according to the degree of hardness required, and when withdrawn are allowed to cool in the crucible. They are now ready for being placed in the cedar cases, but if intended for very fine work, (architectural drawing, for instance,) they must be first heated and then immersed in melted wax or suet, nearly boiling hot, before being fixed in the case. This gives them a certain degree of softness, and preserves their points better. The hardest pencils of the architect have, however, been made of lead melted with some antimony and a little mercury. The common pencils sold in the streets of London are made with the powder of black-lead, mixed with melted sulphur, and poured into moulds which are sometimes reed or rushes. Common carpenter's pencils are of this sort and answer very well for the purposes to which they are applied. Gum arabic and resin are often mixed with the plumbago in common pencils.

Besides the principal use of black-lead in making pencils, it is also employed for counteracting friction, for making crucibles and portable furnaces, and for giving a gloss to the surface of cast-iron. The inferior descriptions of plumbago are largely employed for these purposes.

BLACKING. An article prepared in various ways for the blacking of boots and shoes. Each manufacturer has his own recipe, in which the principal ingredients are oil, vinegar, and ivory-black, or some other sort of blacking matter. In former days shoe-blacks stood in our streets to perform the required operation on pedestrians, but in these days of improved pavements, and greater cleanliness, the brilliancy of the shoe that has received its morning polish at home, is scarcely impaired through the day. Blacking is either liquid or in the form of a paste, and some of the establishments for its manufacture, especially in London, are on the most extensive scale, and are known by their elaborate system of advertising all over the world. Among the various prescriptions for making liquid or paste blacking, the following, which has the title of "patent," is remarkable for the introduction of caoutchouc, which would tend to make the blacking water-proof:—18 ozs. of caoutchouc are dissolved in 9 lbs. of hot rape oil. Add 60 lbs. ivory black, and 45 lbs. molasses, with 1 lb. finely ground gum arabic previously dissolved in 20 gallons of vinegar of strength No 24. The whole to be well triturated in a paint-mill till smooth. Then add in small successive quantities 12 lbs. sulphuric acid, stirring strongly for half an hour. The stirring to be continued for half an hour a day during a fortnight, when 3 lbs. of gum arabic in fine powder are to be added, and the half-hour's stirring to be continued another fortnight. A fine liquid blacking is then produced, and is ready for use. To make paste blacking, the same ingredients and quantities are employed, except that the gum arabic is dissolved in only 12 lbs. of vinegar instead of 20 gallons, and the paste is ready in a week.

BLANKET. See Wool and Worsted.

BLAST. See Bellows and Blowing Machines.

BLAST FURNACE. See Iron.

BLASTING. See Mine and Quarry.

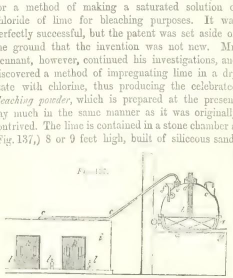
BLEACHING (from the French *blanchir*, to whiten). Calico, muslin, and other cotton fabrics which are sold in a white state, require bleaching, which is also often a preparatory process to dyeing and calico-printing. Linen goods also require bleaching. There is probably no department of the useful arts which has received such direct and obvious benefits from chemical science as the art of bleaching. It was formerly the practice to send all the brown linen manufactured in Scotland to Holland to be bleached. After some preparatory processes, the linen was spread out in bleaching grounds, and sprinkled with pure water several times a-day. In the course of several months' exposure to air, light, and moisture, the goods were bleached. Goods forwarded to Holland in the month of March were usually returned in the following October, but if sent at a later period, they were not returned until the autumn of the following year. The linens thus bleached were called *Hollands*, a name which they still retain.

Many attempts were made to introduce the Dutch method of bleaching into this country. In 1749 bleach-works were established in the north of Scotland with tolerable success. The cloth was first steeped for some days in alkaline leys; it was then washed clean and spread upon the grass for some weeks. This *bucking* and *crofting* were repeated five or six times alternately. The cloth was then steeped for some days in sour milk, washed clean and again crofted. These processes were repeated until the linen was sufficiently bleached, the strength of the alkaline ley being gradually diminished.

This method of bleaching was very expensive, not only from the length of time required in the operation, but also from the large extent of grass-land required in crofting. The constant exposure of large quantities of goods out of doors served as a temptation to dishonest persons, and led to much crime and to severe penal laws against the delinquents. Cases have also occurred in which innocent persons have been shot by spring guns or wounded by man traps, and in one terrible case, a man who was watching his property actually shot his own son, who, after a long absence at sea, was returning home, and walked across the bleach croft as a nearer path to the house.

The first improvement on the old Dutch method, was in the process of *souring*, in which dilute sulphuric acid was substituted for sour milk, the effect of which was to reduce the time required for bleaching, from 8 to 4 months; but the grand improvement in the art was made by Berthollet, who, in 1785, while repeating some experiments on chlorine, which had been discovered by Scheele in 1774, found that an aqueous solution of this substance was capable of destroying vegetable colours, and he was hence led to suggest its application to bleaching. In 1786, Berthollet showed the experiment to Watt, who was then in Paris, and on his return to England he examined the subject practically, and actually bleached 1,500 yards of linen by its means, in the bleach-field of his father-in-law Mr. Macgregor, near Glasgow, who was so well satisfied with the process that he resolved to adopt it at his works. In the following year Professor Copeland of Aberdeen introduced the plan to the bleachers of that neighbourhood, who adopted it gladly. The method soon got into bleach-works generally, but it was found after a short time that the powerful action of the gas was injurious to the workmen, and also to the texture of the goods exposed to it. Berthollet endeavoured to remove the noxious odour by adding potash to the water, by which means a greater quantity of the gas was absorbed, and the solution was then diluted with a considerable quantity of water. The bleaching property of the solution was however destroyed after a time by this method, in consequence of certain chemical changes which took place. Dr. Henry of Manchester substituted lime for the potash, by first passing the goods to be bleached through a stratum of thin cream of lime, and then exposing them to an atmosphere of chlorine; a chloride of lime was thus formed in the cloth, but its action was in some cases injurious. In 1798 Mr. Tennant of Glasgow took out a patent for a method of making a saturated solution of chloride of lime for bleaching purposes. It was perfectly successful, but the patent was set aside on the ground that the invention was not new. Mr. Tennant, however, continued his investigations, and discovered a method of impregnating lime in a dry state with chlorine, thus producing the celebrated *bleaching powder*, which is prepared at the present day much in the same manner as it was originally contrived. The lime is contained in a stone chamber *i*, (Fig. 137,) 8 or 9 feet high, built of siliceous sandstone, the joints of which are secured with a cement of pitch, resin and gypsum. A door fitted into it at one end, can be made air-tight by strips of cloth and clay. A window at each side enables the workmen to judge how the impregnation goes on by the colour of the gas, which is yellowish green. The lime to be impregnated with the gas is contained in trays 8 or 10 feet long, 2 feet broad, and 1 inch deep. These trays are arranged one over another to the height of 5 or 6 feet, and are kept about an inch asunder by means of cross bars. The chlorine is obtained from common salt (chloride of sodium), by the action of black oxide of manganese and sulphuric acid. About 10 cwt. of salt are mixed with from 10 to 14 cwt. of manganese, and then introduced by an aperture at *c* into a large leaden vessel of a nearly globular form. This vessel has an outer casing or jacket of iron *a a*, and steam is admitted at *h* into the interval between the two, for the purpose of communicating heat. From 12 to 14 cwt. of sulphuric acid are introduced in successive portions through a twisted funnel *f*, and the materials are all stirred up by means of an agitator *d b*, the handle of which is on the outside. As the gas escapes from this vessel, it is received into a leaden cylinder containing water: it then enters by a leaden pipe *e* into the top of the ceiling of the stove-room *i*, and being heavier than the air of the room, falls slowly down and diffuses itself through the chamber, where it gradually combines with the lime. After the action has been carried on for about 2 days, the half formed chloride within the chamber is stirred up by means of rakes *l l* from the outside, or a man enters the chambers for the purpose by the doors *k k*: by this means the particles of lime which have not yet absorbed the gas are exposed to its action. The process is then continued for another 2 days, the materials in the leaden retort being frequently stirred up. When all the chlorine is extracted, the contents of the retort, consisting of sulphate of soda and sulphate of manganese, are removed by the tube *g*.

Fig. 137.



The chloride of lime thus formed, is used in enormous quantities in the bleach-works of Great Britain, most of which are situated in Lancashire and in the neighbourhood of Glasgow. As the various processes require an abundant supply of pure water, the works are usually situated near some stream. The substances which require to be removed from cotton goods in order that they may have a pure white colour, are of various kinds. The cotton fibres are covered with a resinous substance, which to a certain extent prevents the absorption of moisture, and also with a yellow colouring matter, which in some kinds of cotton is so marked as to give a distinctive character to the fabric made from it, as in *nankin* or *nankeen*, which is manufactured in China, from a native cotton of a brown yellow hue. Neither the resinous nor the colouring matter has any influence on the strength of the fibre, for the yarn spun from it is as strong after bleaching as before. In some varieties of cotton, the quantity of colouring matter is so small, that the fabric would not require bleaching were it not for the impurities acquired in spinning and weaving. The weavers' dressing of paste, and the rancid tallow or butter used to soften it when it becomes dry, certain soapy and earthy matters, and the dirt of the hands, all require to be removed.

As soon as the goods are received at the bleach-works, the end of every piece is marked with the proprietor's name, which is done with a needle and thread, or with a wooden stamp moistened with coal tar. The fibrous down or nap on the surface of the goods is then burnt off by a process called *singeing*, which greatly improves their appearance, and in the case of dyeing or printing enables the cloth to receive the dye or pattern more perfectly. In this process a number of pieces of cloth are fastened together at the ends by means of long wires, and then wound upon a roller furnished with a winch. The cloth is then drawn over a half cylinder of copper made red-hot by being built into a horizontal flue (Fig. 138). As soon as the cloth has passed over the heated metal, it is wound upon a second roller which plays in a trough of water. The cloth is usually passed three times over the hot surface, twice on the face or the side intended for printing on, and once on the back. It is wound from one roller over the heated metal to another roller on the other side of the furnace, a swing frame being placed for raising the cloth at any moment out of contact with the heated metal, and water is at hand in case of accident to the goods, which is a rare occurrence. By this operation the goods become browned and discoloured. Gas flames are used for singeing thread, muslins, and bobbin-net lace. The flames issue from numerous perforations in the upper surface of a horizontal tube,

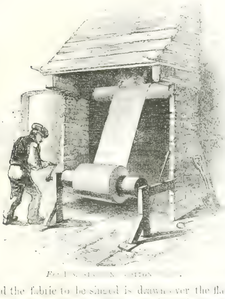
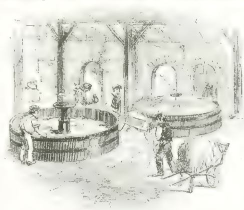


Fig. 1[illegible] SINGEING COTTON [illegible].

and the fabric to be singed is drawn over the flame upon rollers with a rapidity adapted to the texture of the goods. The flame is drawn up through the web by placing immediately over the gas flame a horizontal tube with a slit in its lower surface. This tube is connected with a fan or other apparatus for withdrawing the air from it, and thus increasing the draught of the flame

After singeing, the cloth is steeped in a cistern of water, and, in order to ensure contact with the water, each piece is pulled out, folded loosely, and tied up, with a noose at the end, into an irregular bundle. After soaking 12 or 14 hours, the pieces are washed in a *dash* or *wash-wheel*, which is a hollow, circular, perpendicular wheel, 5 or 6 feet in diameter, and nearly 2 feet in depth. It is divided into four equal compartments by partitions proceeding from the axis to the circumference, each of which has a circular opening on one face of the wheel. (Fig. 139.) Water is admitted into the compartments by a pipe concentric with the axis on which the wheel rotates. The pieces to be washed are put into the compartments through the circular openings in front, and water being admitted, the wheel is made to rotate rapidly, and thus wash the cloth with considerable agitation. The object of this washing is to remove as much of the dirt and weavers' dressing as possible; but, as the grease cannot be removed except by making it soluble by the action of an alkali, lime is economically employed. The pieces are therefore boiled with lime in a large circular boiler, or keir, called a *bucking* or *bowking-keir*, or *puffer*, shown in section in Fig. 140, while in Fig. 141 one of these keirs is represented in action, and another in the course of preparation. It consists of a pan of wrought-iron, set in brickwork, on which the fire acts, and an upper part of cast-iron for containing the goods. The two parts are separated by a false bottom of cast-iron, and in the centre is an iron pipe furnished with a curved cover. The liquor in the pan, from the pressure of the goods above it, does not boil until it is some degrees above the boiling-point; the liquor boils first in that part of the pipe where the pressure is less than it is in the pan, so that a mixture of steam and water being formed there, rushes up the pipe, and is reflected back by the cap upon the goods, thoroughly drenching them with the hot alkaline liquor. This discharge is followed by another portion of the heated alkaline liquor, which, rising into the pipe, boils and escapes at the top as before. In this way the action goes on, and the liquor, gradually filtering through the goods, finds its way back again into the pan, to be again heated and discharged as before. In preparing a keir, 1 lb. of lime is used for every 30 or 40 lbs. of goods; the lime is formed into a cream in a separate vessel.

Fig. 140.



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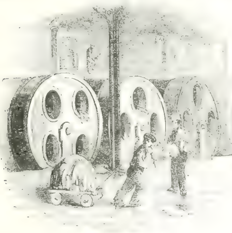

Fig. 1[illegible] [illegible]

and is gradually spread over the goods as they are deposited in layers in the keir; the requisite quantity of water is next added, and heat is applied. The liquor is about two hours in boiling, and the process is continued for about seven hours. The effect of the lime is to darken the colouring matter of the cotton, so that after washing they appear darker than they did before; but all the dirt and grease are removed by this process. The goods are next washed in the dash-wheels, in order to remove the adhering lime, and then comes the *chemicking*, or steeping in a very dilute solution of chloride of lime, for which purpose they are placed in stone vats, over the centre of which is a perforated trough, into which the bleaching solution is pumped up many times during the process, and from this it drains down upon the goods. Every pound of cloth requires about half a pound of chloride of lime, of a certain strength, mixed with about three gallons of water. The steeping is continued six hours, after which the cloth is of a light grey colour, not white, but considerably improved in appearance. Care must be taken to make the steep of the proper strength, for if too strong, the calico will run into holes.

In the next process, which is called *souring*, the goods are steeped for four hours in water soured by sulphuric acid, when a minute disengagement of chlorine takes place throughout the substance of the cloth, and it immediately assumes a bleached appearance. The acid also removes a small portion of oxide of iron contained in the fibre, and also the lime of the previous processes. When removed from the acid, the goods are again washed: they are greatly improved in appearance, but still not quite bleached. They are therefore boiled for eight or nine hours in a potash or soda ley; then washed at the dash-wheel; again steeped for five or six hours in a solution of bleaching-powder, two-thirds of the strength of the first solution; then soured as before for two, three, or four hours, according to the quality of the goods, and at length they are perfectly bleached. Every trace of acid is removed by careful washing, for if any acid were left in the cloth, it would corrode it, especially when heated. The acid favours the bleaching action, and does not injure the fibre of the cloth, although the steeping is continued for days, provided the cloth is not allowed to dry with the acid in it, or be left above the surface of the liquor. The acid is also necessary to remove the caustic alkali, which adheres with great pertinacity to the goods. The goods lose weight in being bleached. Fine calico loses nearly 10 per cent.; but of this, one-half is the weavers' dressing. In coarse goods the loss is greater. For the processes subsequent to bleaching we must refer to the article CALENDERING.

The above details refer chiefly to cotton shirting, and the better descriptions of calico used for printing on. The processes are modified for different varieties of cotton goods. It is also often necessary to expedite the various processes. As an example of the rapidity of bleaching by the new method, compared with the old, we may mention one case in which a Lancashire bleacher received 1,400 pieces of grey muslin on a Tuesday, and on the Thursday following they were returned bleached to the manufacturers, at the distance of sixteen miles, and were packed up and sent off on the same day to a foreign market.

In bleaching linen, the processes are similar to those already given, but are continued longer on account of the firmer hold which the colouring matter has on flax. This colouring matter does not appear to be chemically combined with the fibre until the plant is steeped in water, in the process of *retting* [FLAX]. Hence, to save the expense of bleaching, it has been proposed to separate the woody fibre by drying the plant, instead of steeping it, and then to beat off the woody parts by means of mallets. The linen can then be bleached by a simple washing in water.

In all these processes the efficient bleaching agent is the chlorine, but the precise method in which it acts is not well understood. Perfectly dry chlorine does not bleach at all; but when dissolved in water, its bleaching power seems to arise from its decomposing a portion of the water, the oxygen of which unites with the colouring matter, and renders it soluble in water or a weak acid solution. The bleaching power of dew and of rain-water is referred to the excess of free oxygen which they contain. But according to another view, the organic colouring matters being compounds of carbon, hydrogen, oxygen, and sometimes nitrogen, the chlorine acts directly upon them with decomposition, uniting with the hydrogen to form hydrochloric acid, and setting the other components free, or rendering them soluble. For example, writing-ink is a compound of sesquioxide of iron and an organic substance named *tannin*. The chlorine will combine with the tannin or one of its elements, and cause the written characters to disappear. If the paper be now moistened with a solution of prussiate of potash, it will unite with the sesquioxide of iron, and the characters will reappear. If, however, after the tannin has been removed by the chlorine, the paper be washed over several times with very dilute hydrochloric acid, the writing will be completely destroyed. Chlorine has no action on Indian ink or on printer's ink, because the colouring matter in these cases is minutely divided carbon, which does not combine directly with chlorine.

Bleaching powder varies greatly in strength, and it is of importance to the manufacturer to be able to determine its value, or the quantity of chlorine contained in a given sample. Many methods have been recommended for this purpose. Professor Graham's method is simple in practice, and depends on the effect of the chlorine of the bleaching-powder in peroxidizing a proto-salt of iron, of which two equivalents require one of chlorine. The chlorine acts by decomposing water, and liberating a corresponding quantity of oxygen. 78 grains of green sulphate of iron are dissolved in about 2 ounces of water, and acidulated by a few drops of sulphuric or hydrochloric acid. This quantity will require for peroxidation exactly 10 grains of chlorine. 50 grains of the bleaching-powder to be examined are next rubbed up with a little tepid water, and transferred to an alkalimeter, [see ALKALIMETRY], which is filled up to zero with water, and the contents well mixed by agitation. "The solution of chloride of lime being thus made up to 100 measures, is poured gradually into the solution of sulphate of iron, till the latter is completely peroxidized, and the number of measures of chloride required to produce that effect observed. The change in the degree of oxidation of the iron solution is discovered by means of red prussiate of potash, which gives a precipitate of prussian blue with a salt of the protoxide of iron only, and not with a salt of the peroxide. By means of a glass stirrer, a white stoneware plate is spotted over with small drops of the prussiate. A drop of the iron solution is mixed with one of these after every addition of chloride of lime, and the additions continued so long as a deep blue precipitate is produced. The liquid may continue to be coloured green by the iron salt, but that is of no moment. The richer the specimen of chloride of lime is in chlorine, the fewer measures of its solution are required to peroxidize the iron, the number of measures containing 10 grains of chlorine always producing that effect. The quantity of chlorine in the 50 grains of bleaching-powder is now known, being ascertained by the proportion, as the number of measures poured out of the alkalimeter is to 10 grains of chlorine, so 100 is to the total grains of chlorine. In a particular experiment, the 78 grains of sulphate of iron required 72 measures of the bleaching solution. Hence, as 72 is to 10, so 100 is to 13.89 chlorine in 50 grains of the chloride of lime. The quantity of chlorine in 100 grains of the chloride, or the per centage of chlorine, is obtained by doubling that number, and was therefore in this instance 27.78 per cent. or 28 per cent." [1]

According to Professor Brande, "the best samples of commercial chloride of lime contain on the average not more than 30 per cent. of chlorine, and when chlorine is passed over hydrate of lime, in an experiment upon the small scale, it cannot be made to absorb more than about 40 per cent.; but if the hydrate of lime be diffused through water, it will then absorb more than its own weight of chlorine, and we form a solution containing one equivalent of lime (or of hydrate of lime) and one of chlorine, which is the true atomic compound, and is dissolved out of bleaching-powder by the action of water." [2]

The bleaching of wool is performed by a process called *sulphuring*, in a close apartment in which sulphur is burning. The goods are hung on poles, so disposed that the sulphurous acid can readily penetrate them. When the chamber is filled, a quantity of sulphur is placed in flat broad dishes, and, being ignited, it is allowed to burn away gradually, and in the course of some hours the colouring matter is destroyed. In bleaching mousselins de laines (which are formed of cotton and wool), the goods are usually passed two or three times through a solution of soap and soda at about the temperature of 130°, and then sulphured for several hours. After this they are passed through a very weak solution of caustic soda, dried, and usually impregnated with a dilute solution of tin, which imparts considerable brilliancy to the colours afterwards applied to the goods.

Other varieties of bleaching will be noticed under the articles, PAPER, SILK, WAX, &c.

BLENDE. The native sulphuret of zinc, called by the miners *black-jack*. [See ZINC.]

BLOCK. A block is a pulley or *sheave*, revolving on a fixed axis or *pin* within a chamber or *mortice*, cut out of a solid block of elm, ash, or other tough wood, which is called the *shell*. The sheave is a circular piece of wood, usually lignum vitæ, but sometimes of brass or cast metal, with a groove on the edge for the reception of the rope. In the best blocks, called *coaked* sheaves, the sheave has a brass bush fitted in the centre, with a hole through it for the pin, as in Fig. 142. The pin is usually of iron, but sometimes of lignum vitæ, or other hard wood. It is supported by passing through the sides of the shell. Some blocks are made to accommodate 2, 3, and even 4 sheaves, in which case there are as many separate mortices. If the sheaves are placed side by side the same pin serves, but if placed one above the other, then of course there are separate pins. In nautical language the block with its rope is called a *tackle* of single or double blocks. Each block is furnished with a band or strap, terminating in an eye of rope or an iron hook, for attaching it to an object on which it is intended to act as a mechanical power, while another block is suspended from some fixed support. The former is called a *running* block, and the latter a *standing* block. The shells of very large blocks are made up of separate pieces strongly bolted together; these are termed *made* blocks. Blocks are also termed *thick* or *thin*, according as they are adapted to the reception of large or small ropes.

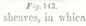
Fig. 142.

Blocks are chiefly employed in the rigging of ships, to assist in raising or lowering the masts, yards, and sails. They are also available as a mechanical power under a great variety of circumstances. There is a description of block without sheaves, termed *dead-eyes*, used for setting up and fastening shrouds, and other standing rigging, sheaved blocks being chiefly used for the running rigging.

It would be quite impossible within the limits of this article, even if it were desirable, to describe the various forms of blocks used in the navy. A few, however, may be noticed. Fig. 143 is called a *snatch-block*. It consists of a single sheave, with a notch cut through one of the cheeks, to allow the rope to be lifted in and out of the block without putting its end in first. In this example, the strap does not surround the block, but is put through a hole at one

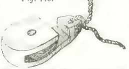
Fig. 143.

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(1) Graham's "Elements of Chemistry."

(2) "Manual of Chemistry." [illegible]

end. This is a convenient block for hauling a rope.

In Fig. 144 the block is iron-bound, terminating at the notched end in a swivel hook or eye-bolt large enough to receive several turns of lashing, by which the block is attached to the fixed support. That part of the strap over the notch in the side lifts up with a hinge, and is confined down when the rope is in the block by a small pin passed through an eye in the hinge part of the strap. The strap at the other part of the block is let into the wood, and is kept to its place by nails. This block is used where a warp or hawser is brought to the capstan.

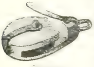


Fig. 144.

Fig. 145 is a long tackle block, consisting of two single sheaves, one above the other in the same block. The lower one is $\frac{2}{3}$ the size of the upper; and is used in combination with a common single block to form long tackle for loading or any other purchase.

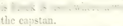


Fig. 145.

Fig. 146 is a *clue garnet* block with a single sheave. This is suspended from the yards by a strap with two eyes, and a lashing surrounding the yard, and passing through the eyes. These blocks receive the clue garnets, or ropes which haul up the clues of the sail, and are applied to the main and fore-yards. Clue-line blocks serve the same purpose, but are applied to the top-sails, top-gallant, and sprit-sails. These blocks were improved by Brunel. In the old form the rope had a tendency to get entangled with the sail, and to slip out of the groove of the sheave. In the improved block two holes are made for the purpose of passing the rope in and out. The sheave is in the centre of the block, so as to be entirely included, except the mortice, where the sheave is put in. The strap surrounds the lower part of the block, and both ends of it pass through the hole in the upper part, where they cross each other; they are then formed into an eye, by which the block is suspended from the yard. In this arrangement the parts cannot get out of place, as the garnet or rope is so much confined within the block, nor can the sail be driven into the block as in the old form.

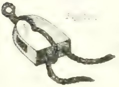


Fig. 146.

Fig. 147 is a shoulder block. A large single block left nearly square at the upper end and cut sloping in the direction of the sheave. It is used on the lower yard-arms to lead in the top-sail sheets, and on the top-yards to lead in the top-gallant sheets, which by means of the shoulder are kept upright, and prevented from jamming between the block and the yard.

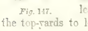
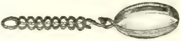


Fig. 147.

Fig. 148 is a *spring* block, invented by Mr Hopkinson of Philadelphia, to assist a vessel in sailing by increasing the acting spring of her rigging. This consists of a common block with a ring or eye, into which a spiral spring is linked at one end by a hook, and at the other by a ring, which is to be annexed to an eye-bolt at the timber head or other point of application. Two of these blocks are used, one to the timber heads, and the other to the sail. Passing through the spirals of the spring chain is another chain called the check chain, which is connected by links to the hook and to the ring, to prevent the spring being drawn out too far, and thus damaged. Vessels provided with these spring blocks are less liable to heel, and will receive the impulse of the wind to better advantage, but the plan does not seem to have been adopted to any great extent.

Fig. 148.



Among the forms of block used in the navy, some are named after their shape, as D blocks, *Shoe*-blocks, *Nine-pin* blocks. Others are named from a family likeness, as *sister*-blocks, which are two similar single blocks formed out of one solid piece.

Before the introduction of machinery blocks were made in the following manner:—The shells were sawed to the proper length and thickness; the corners were then sawed off; the workman then gauged or marked out the size of the mortice or sheave-hole in the middle, $\frac{1}{16}$th larger than the thickness of the sheave. In single sheaved blocks the thickness was larger than the diameter. In blocks of two or more sheaves the partitions between them were $\frac{1}{8}$th less than each mortice. The block was then jammed up edgewise in a frame, and the mortices gouged out with an auger, and the wood sawed out with a rib saw. The holes were further cleared out by chisels and by burrs at the corners. The pin-hole was next bored through the middle $\frac{1}{10}$th less than the diameter of the pin. The outsides and edges of the block were then rounded off by shaves. The scores or grooves for receiving the strap were made, and the sheaves were then fitted. These were $\frac{1}{10}$th thicker than the diameter of the rope intended to run on them, and 5 times that thickness in diameter. The sheave being nicely bored was put into the lathe and turned smooth, and the groove on its circumference was hollowed out to a depth equal to $\frac{1}{3}$d of its thickness, so that the rope might embrace it closely. The diameter of the pin was that of the thickness of the sheave. The pin was turned cylindrical, except the head, which was left octagonal to prevent it from turning in the block. After the sheave was fitted by driving the pin through the block and sheave, one end of the block was hollowed out to admit the rope, and a small neat chamfer was taken off the edges. The whole block when finished usually formed an oval spheroid flattened at the opposite sides.

The manufacture of an article apparently so trifling as that of a ship's block, seems scarcely to require the assistance of much machinery, or to entail any very great expense on the country; but when it is considered that a single 74-gun ship requires not less than 1,270 blocks, besides 160 dead eyes, and other small articles of a similar kind, all absolutely necessary to the working and even to the safety of a ship, it will readily be supposed how difficult it must be to maintain the supply if made by hand, and how great the expense. The immense demand for blocks during the long protracted war, had called the attention of the Admiralty and Navy Board to the possibility of making some reduction in the expense of this important article. About the year 1801, Mr. M. I. Brunel, an ingenious mechanic from America, had completed models of certain machines for the construction, by an improved method, of the shells and sheaves of blocks. This model was submitted to the Lords of the Admiralty, and by them referred to General Bentham, the Inspector-general of Naval Works. The advantages of machine-made blocks were stated to be, *first*, in ensuring regular and determined dimensions; *secondly*, in adding strength where it was wanted, by making the head and bottom more substantial, and less liable to split; and *thirdly*, in leaving the wood between the two mortices thicker, so as to admit a sufficient bearing for the pins. The uniformity and exactness with which these blocks were to be made would also make it difficult to counterfeit them, and this would act as a precaution against embezzlement. Another great advantage would be the using up of much waste wood in the dockyard, usually sold for a trifle for fire-wood, &c. The sheaves would also be made so true to each other, that every sheave of any particular size would equally fit any shell of the size for which it was intended; and the inconvenience to which ordinary blocks are liable from the friction of the ropes against one or alternately both of the sides of the mortices, was to be removed by placing a sheet of metal on the upper part of the mortice, bent to the proper shape by an engine adapted to the purpose.

General Bentham reported that by the new method there would not only be a great saving, but also an increase of strength, durability, and facility of working in the new blocks. Accordingly, those parts of the machinery which had been secured by patent were removed to Portsmouth in 1804, and were put in operation, while other machines necessary to the completion of the whole scheme were at work by 1808. From that time to the present the whole has gone on without any alteration or assistance from the inventor, and is so complete in all its parts that the attendance of a few common labourers under the direction of the master of the wood-mills is quite sufficient. This collection of machines is one of the most ingenious and complete that was ever invented for forming articles in wood; so that not only blocks, but other articles in wood can be produced, the machines performing most of the practical operations of carpentry with the utmost accuracy and despatch. The largest timber can be converted and sawed up into any scantling, by several circular and reciprocating saws adapted to various purposes. Some of the operations performed by the smaller machines are boring, mortising, turning in wood and iron, riveting, drilling, broaching, burnishing iron pins, &c., operations which were formerly supposed to be chiefly or entirely dependent on the skill and dexterity of the workman. These machines are set in motion by a steam engine of 32-horse power, which is also used for various other purposes in the dockyard. Under this system 4 men can do the work of 50 in making shells, and 6 men can do the work of 60 in making sheaves. These 10 men thus displacing 110 can easily finish in one year 130,000 to 140,000 blocks of different sorts and sizes, of the value of 50,000*l*., this being the average annual number and value from the year 1808 to the conclusion of the war. Brunel was engaged in completing this system from September 1802 to June 1808, his allowance during that time being 1 guinea a day. On the completion of the system it was agreed that the savings of one year as compared with the contract prices was a fair remuneration. These savings were estimated at 16,621*l*., to which we may add the six years' allowance at 1 guinea per day, amounting to 2,400*l*., and for the working model 1,000*l*., making the total amount received by Brunel about 20,000*l*., a very fair and moderate remuneration, especially when it is considered that the expenses of the buildings for the new machinery, the machinery itself, the steam-engine, the interest of money, were all completely cleared off by the savings of four years. Such was the importance attached by the government to this invention, that a complete set of duplicate machinery was erected in the Dock Yard at Chatham, and kept in constant readiness for action in case of any accident to the machinery at Portsmouth. Hitherto, however, the duplicate machinery has not been wanted.

The machinery was constructed by Mr. Maudslay, of the Westminster-road, London. The framing of the machinery was of cast-iron, and those parts exposed to violent and rapid motion were of hardened steel. The writer of the article in Rees's Cyclopædia, in which this machinery is minutely described, in speaking of its excellent construction, remarks, that "well-constructed machinery, though expensive in the erection, is cheaper in the end than imperfect works, which require constant repair, the expense of which is the least evil; as it generally happens that a machine will fail at that time when it is most wanted, in consequence of being then most worked; and the loss occasioned by the stoppage of great works, particularly where many people are employed, is too evident to require notice. In the same manner, an attention to neatness in the appearance of machinery has its advantages, by inducing the workmen to be careful of the machines they work at, to preserve them from the slightest injury, and to keep them clean from dust, which, trifling as it may appear, is a very essential point in the preservation of those parts which are in rapid motion, with friction against other parts, for dust getting between such surfaces grinds them away very fast, and in their most essential points."

We will now notice the machines, and the operations connected therewith, referring to larger works for a more detailed description.[1]

1. *The straight cross-cutting saw.* This is used for cutting up into lengths the elm-trees, of which the shells of the blocks are to be made. The log is introduced through one of the windows of the wood-mill upon a very low bench below the saw, which is lowered, and made to rest with its teeth upon the log, the back being retained in the cleft of the guide. When the crank is set in motion, the saw moves backwards and forwards, exactly as if worked by hand, and quickly cuts through the tree. After the saw has cut to some depth it gets out of the guide, and is sufficiently deep in the wood to guide itself, for in cutting across the grain of the wood it has no tendency to move out of the true line. When the saw has cut off a piece from the log, its handle is caught by a fixed stop, the machine is thrown out of gear, a man lifts up the saw by a rope, and the block is advanced to receive a fresh cut. This saw is used for the largest trees only.

2. *The circular cross-cutting saw,* used for the smaller trees. The axis of this saw is parallel to the length of the tree to be cut; but is so mounted that it can be moved in all directions, either raised up or moved aside; but in all these motions its axis continues parallel to itself, and the saw continues in the same plane. These motions are produced by two winches, each provided with a pair of equal pinions, working a pair of racks fixed upon two long poles. The spindles of these winches are fixed in two vertical posts, which support the axis of the upper frame. One of these pairs of poles is jointed to the extreme end of the upper frame, so that by turning the handle belonging to them the frame and saw are raised or lowered. The other pair of poles is attached to the lower part of the saw frame, so that the saw can be moved sidewise by means of their handles, which then swing the saw from its vertical position. These handles give the workman complete command of the saw. By means of one of them he draws the saw against one side of the tree, which is properly secured, and cuts it about half or one-third through; by the other handle he raises the saw up, draws it against the top of the tree, and cuts it half through from the upper side; he then depresses the saw, and cuts it half through from the next side; and lastly, a trifling cut at the lower side separates the block, and the tree is then advanced for another cut.

3. *The reciprocating ripping-saw* cuts these blocks in the direction of the grain into two, three, or more pieces, in one direction, and then in a direction perpendicular to the former, so as to reduce the logs to the size of the required blocks. The action of this saw is similar to that of No. 1.

4. *The circular ripping-saw,* for smaller sizes than No. 3. This is a thin disc of steel, with teeth formed in its periphery: it is fixed to a horizontal axis just below the surface of a bench, so that a portion of the saw projects through a slit a few inches above the bench. A rapid rotatory motion is given to it by a strap passing over a pulley at the further end of the axis. The workman places the block with one side flat upon the bench, and sliding it forward against the saw, it is cut through with great precision and rapidity.

5. The blocks having been cut to the proper size by the saws, are placed in the *boring-machine,* Fig. 149. This machine has an iron frame A A, with three legs, between which the block is introduced, and the screw B being forced down upon it, confines it to the proper place for the borers D E to act upon it. The end of the screw B has a steel ring fitted upon it, the lower side of which is a sharp edge. When the screw is whirled round, the balls at the end of its cross handle cause it to act as a fly-press, to stamp the impression on the end of the block. The exact position of the block is ascertained by a piece of metal, (Fig. 150,) fixed just beneath the point of the borer E. This piece of metal adjusts the position for the borer D, and its height is regulated by resting on the head of the screw *x*, which fastens the piece X down to the frame. The sides of the block are kept parallel by being applied against the heads of three screws, represented by dotted lines, in the double leg of A. The borer D bores the hole for the centre-pin; the borer E makes the holes for the commencement of the sheave-holes. The borers are of the same form as a carpenter's centre-bit, and each is screwed upon the end of a small mandril mounted in a lathe-frame G and H. These frames are fitted with sliders upon the edges of the flat bars *i k*, the former being secured to the

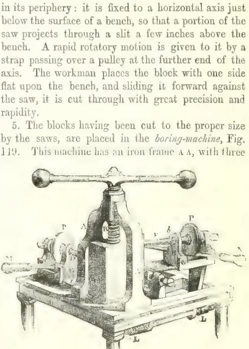
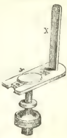


Fig. 149. THE BORING MACHINE.

Fig. 150.



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[1] The reader interested in the subject is referred to the 2nd volume of Rees's Cyclopædia, and also to the 3d volume of Brewster's Edinburgh Cyclopædia. To the latter authority we are indebted for the description of the illustrative figures of the machines numbered 5 to 9.

frame, and the latter being fixed upon a frame of its own, moving on the centre screws L L, beneath the principal frame of the machine. In this way the borer E can be moved within certain limits, so as to bore holes in different positions, and these limits are determined by two screws, one at *a*, and the other on the opposite side. A projecting piece of metal from the under side of the slider *k* of the borer E stops against the ends of these screws, to limit the excursion of the borer. The frames for both borers are brought up towards the block by the levers M N, which are centred on a pin at the opposite sides of the frame of the machine, and have oblong grooves through them, which receive screw-pins fixed into the frames G and H beneath the pulleys F F, which give motion to the spindle.

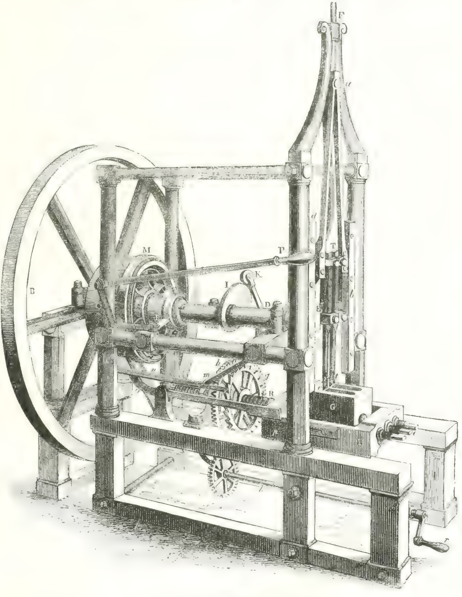


Fig 151 THE MORTISING MACHINE.

The block being applied with one of its sides against the three screws in the double leg, and resting on the screw *x*, is thrust up against the stop X, Fig. 150. The screw B is then brought down, which holds it fast, and the workman takes the handles M N, and forces them towards the block. This brings the borers against it; and, as they are in rapid motion, they will bore as fast as they can be brought up to the work. This is the method of boring a single sheave block, when the screw-stops at *a* are screwed so far as to confine the frame *k* in a vertical position, and then its borer makes a hole through the centre of the block. For a double block the screws are withdrawn so far that when the frame is held against one screw its borer will be in the proper place for one hole; and when inclined to the other screw, it will be in the proper place for the other hole; and this distance between the holes can of course be increased or diminished as required to suit thick or thin blocks. The borers can be unscrewed near the ends of their spindles at *b*, to put on one of a larger or smaller size. The points of the screw-centres at L, on which the frame of the borer E vibrates, can be put into different holes in the frame, so as to alter the difference of level between the two borers, to suit blocks of different sizes; and the screw *x* is changed for one with a thicker head, or a washer is put upon its head. The stop X can be altered in position, by sliding it further from or nearer to the frame.

6. The block thus prepared by the boring machine is taken to the *mortising machine*, Fig. 151. This machine is moved by an endless band passing round a drum at A, screwed to a fly-wheel B. This drum turns an axis D, at the extreme end of which is a crank, with a long rod extending from it up to a joint at *a*, by which it is connected with a frame E, fitted between sliders *b d*, and guided by a cylindrical rod F, sliding through a fixed collar. In this way the frame is moved up and down when the axis D revolves. To this frame the chisels are attached, and operate upon the block fixed at G in a carriage H, sliding horizontally in the frame of the machine. At *e* are three screws of the same size as the screw B of the boring-machine, each furnished with a similar ring at the end. This ring enters the impression made by the boring-machine, so as to fix the block in its proper position when the screw is turned. This forces the other end of the block against the cross-bar of the carriage, which has three steel circles fixed to it opposite the end of the screw *e*. Each of these rings includes two smaller rings with a sharp edge, and the pressure of the screw *e* forces the block against these rings, and prints their figure in the wood. By this contrivance the block is held quite fast in the carriage while being mortised. Behind the carriage is a large double-wormed screw R, and this is received through a nut turning round in a fixed collar, supported by a bar across the frame. To this nut two wheels *g h* are fixed: the former is a large ratchet-wheel; the latter a cog-wheel with a smaller one gearing with it, and fixed to the end of a long axis *k* furnished with a winch *r*. When this is turned round by hand, the nut of the screw is also turned, and the carriage is moved slowly backwards or forwards. In this way the carriage is adjusted to the proper point for beginning the work. The gradual advance of the block to each cut of the chisel is produced by turning the ratchet-wheel *g* by the following contrivance. The axis D has an eccentric circle I fixed upon it, which as it revolves acts upon a roller K fixed in one arm of a bent lever; the other end of this arm has a rod *m* jointed to it, with a tooth in the middle, which engages the teeth of the ratchet-wheel, and turns it round, a tooth at a time, as the rod moves backwards and forwards. The extreme end of this rod rests upon a lever *n* (except when being drawn over the sloping side of the tooth of the ratchet-wheel), the centre of which is a pin fixed in the vertical column of the frame. It is held up by a second lever, *o*, supported on a cock screwed on the frame. The opposite end of this lever is made so heavy that its weight is sufficient to raise up *n* and *m*, so that the tooth of the latter will be too high to intercept the teeth of the ratchet-wheel in its motion. The heavy end of the lever is kept up by a piece of metal fastened to the side of the carriage, at *p*, by screws passing through oblong grooves, so that it can be attached at any part along the length of the carriage. By this means, when the carriage has advanced as far as required, the loaded end of the lever *o* falls off the piece *p*, and disengages the rod *m* from the ratchet-wheel. The fly-wheel and drum which turn the machine are fitted on a cylindrical part of the axis, so as to move freely thereon when it is not required to work the machine. A conical wheel S, with a hollow axis or tube centre-piece, is fitted upon the axis D so as to slide freely endwise, but is confined to revolve at the same time by fillets inserted in it. The end of the tube of the wheel S is formed into a circular groove, which is embraced by a forked lever L, centred in the opposite side of the frame. By moving the end of L towards the fly-wheel, the conical wheel S is thrust forward, and jammed into the inside of the drum A. This exactly fits the wheel, and the friction caused by the contact of the two conical surfaces is sufficient to work the machine. But when the lever L is pulled away from the fly-wheel, the conical wheel is drawn out from the rigger, and the fly-wheel detached from the axis, so as to revolve upon it freely without turning it.

In using this machine the block is applied with its screw mark to the end of one of the screws *e*. If a double block is to be mortised, as in Fig. 151, the centre screw is used; but if 2 single sheaves are to be fixed in, the 2 outer screws are used. By screwing it tight, the block is fixed between the double circle points before mentioned. To guide the block to its proper position, so that the hole bored for the commencement of the sheave hole shall be vertical, the block being fixed, the handle *r* is turned till the hole is brought beneath the sliding frame. The chisels are now adjusted. These are long square bars of steel TT, fastened to the frame by a clamp. The back of each chisel has a small piece of steel attached for thrusting out the chips which it cuts, to prevent the hole from being clogged up. It has also two small cutters or *scribers*, fixed perpendicular to its edge, and projecting rather before it, so that in the descent of the chisel, two small clefts are cut or scribed, which include the width of the chip to be cut out by the chisel in the succeeding stroke. By this means the mortice has its sides perfectly smooth. The back of the chisel is rounded to conform to the hole bored in the boring machine.

The clamp to which the chisels are attached passes behind the cross-bar of the frame, and the chisels being put exactly over the holes which are to become sheave-holes, are screwed fast by means of clamps. The machine is now put in motion by depressing the handle r, which is at the end of a lever, the fulcrum of which is a pin fixed in the column of the frame at *s*, and a short arm gives action to the end of the lever L, so as to put the machine in motion. At the first descent of the chisels, they cut down through the whole depth of the holes previously bored, so as to give them a flat side when they rise up. The eccentric circle I, moving the bent lever and rod *m*, turns the ratchet wheel round on both and advances the block through a small space in the direction of the fly-wheel, so that the chisels in descending cut a fresh space, and in ascending the block advances. In this way the sheave-holes are rapidly cut, each chisel making from 110 to 150 strokes per minute, and cutting at every stroke a chip as thick as pasteboard with the utmost precision. When it is completed, the loaded end of the lever *o* drops off the piece *p* previously adjusted, and raises the rod *m*, so that the further advance of the block is prevented. The attendant then raises the handle P, which stops the machine. The finished block is now removed and a fresh one put in: the handle r is screwed back to bring the block to the proper point, and the machine is set in motion as before. By an adjustment of the cross bar in the back of the carriage, the mortising machine is adapted to blocks of different sizes, and the frame E may have any number of chisels fixed to it corresponding to the number of mortices required to be cut.

7. The corners of the block are next cut off by means of the *corner saw*, Fig. 152, which consists of a mandrel mounted in a frame A, carrying a circular saw L on its extremity. The frame of this mandrel is screwed down upon the frame BB, which is supported by four columns. CC DD is an inclined bench or trough, in which a block, as E, is laid, being supported on its edge by the plane C, and its end kept up to its position by the other part of the bench D. By sliding the block along this bench it is applied to the saw, which cuts off its four angles in succession, by applying its different sides to the trough. In the figure, two of the angles have been cut off and the third is just marked by the saw. By laying pieces of wood of different thickness against the plane D, so as to fill it up, the block is kept nearer to or further from the saw, and in this way different sizes of blocks can be cut.

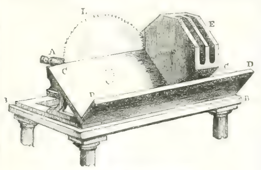


Fig. 152. THE CORNER SAW

8. The blocks thus prepared have their outside surface formed to their true figure by means of the *shaping machine*, Fig. 153, the principal part of which is the chuck which holds the blocks. This consists of two equal wheels, A, B, mounted on the same axis, A being firmly fixed, while B slides upon it so as to render the space between them greater or less, as may be required for blocks of different lengths. This is effected by means of five bolts and nuts, the heads of the nuts being shown at *x*. Both wheels are divided into 10 equal parts. At each of these on A, a short axis or mandrel is fitted through a projecting part of the rim of the wheel. On the outside of the wheel each of these mandrels has a small wheel *a* fixed upon its end. On the ends in the inside of the wheel the mandrels have each a short cross-bar fixed, sufficiently long to contain two steel rings, which are exactly the same size and distance apart as those in the morticing machine, which support the block. The wheel B has at each point opposite the mandrils *a*, a screw centre similar to the back centre of a lathe, but furnished at its point with a steel ring of the same size as that at the end of the screw of the boring machine. The blocks are held in between the wheels by putting the double point at one end of each block, against the double rings at the end of one of the mandrels; and then, screwing the screw in the other wheel tight up, the block is confined between them. In this manner the chuck being filled with 10 blocks, if they are turned round rapidly and a chisel or gouge be fixed for them to cut against, each will be formed to a segment of the circle in which they move. This gouge is supported in a frame moving on a fixed rest D, which is curved to a circle whose centre is in the centre of the chuck. It is confined to move on this arch by a curved radial bar E, fitted to centre on the floor beneath the machine at one end, and having the other attached to the frame F which supports the tool. This frame contains a slider *f* moving in a groove, and at the end carrying the tool *g* in a holder. The slider has an axis or spindle fitted perpendicularly in it at *h*. On the lower end of this is a roller, which applies itself against a curved piece of metal *i*, called a *shape*, fixed upon the framing. The roller is kept in contact with the shape by a lever centered at *k* on the frame F, and connected by a short coupling iron with the slider *f*; so that when its handle *l* is pressed towards the machine, the roller is kept up to the shape. By means of a handle G jointed to the frame F, which carries the tool and all its apparatus, this frame can be moved along the rest D, being guided by the radial bar E in its motion. Now if the other handle *l* be at the same time pushed forward, the roller applies itself to the shape, and the gouge describes the same curvature as the shape. Below the first shape is a second *m*, and by a simple movement the roller can be depressed so as to roll in the second shape, and give the curvature of it to the tool instead of the upper one.

Supposing the 10 blocks to be fixed as just described, the frame F of the gouge is turned to one end of the rest D, and the chuck put in rapid motion, by a band round a pulley H, on its axis. The attendant, with the handle G in his right hand and *l* in his left, sweeps the frame along its rest by the handle G, while he keeps the roller in contact with the shape, by pressing the lever *l* towards the machine. In this movement, the gouge cuts to their proper curvature the faces of all the 10 blocks which are farthest from the centre. When the frame has slowly traversed the whole length of its sweep, the outside faces of all the blocks are finished, and the machine is stopped by casting its movement off from the mill. But as it preserves a considerable velocity, this is checked by a steel spring at I, fixed at one end to the frame, and extending round a wheel fixed on the pulley H. The other end of this spring has a handle, which being pressed down, the curved part of the spring encloses the wheel and acts as a gripe. When the motion ceases, the blocks are all turned one quarter round on the small mandrels *a*, by an endless screw on each of the wheels *a*. These screws are cut in the ends of as many spindles *d*, pointing towards the centre of the chuck. At the ends of those nearest the centre, each spindle has a small bevelled wheel *e* fixed upon it. There is also a large bevelled wheel K fitted upon the axis, between the wheel A and the pulley H, so as to slip freely round upon the axis, and when it is turned round, it will evidently turn all the wheels, spindles, screws, and mandrels at once, and thus turn all the blocks so as to bring another face outwards. While the chucks are turned round, the wheel is held fast, and the wheel K is stopped by a catch L, moving in a joint fixed on the ground. This wheel being detained, the attendant takes hold of the chuck by its rim and turns it round 4 times, and the bevelled and other wheels are so proportioned that those 4 times will make the blocks revolve exactly one quarter on their separate axes, so as to bring another side of each block outside. The machine is then set in motion as before, and the work is alternately stopped and carried on until all four sides are finished, the upper shape being employed to cut the third side in the same manner as the first, and for the second and fourth sides, the lower shape is used. By means of a screw *m*, the socket supporting the axis of the roller *h* can be moved along the slider, the effect of which is to project the tool *g* more or less beyond the shape, as may be required to cut larger or smaller blocks. The same shapes will serve for several different sizes.

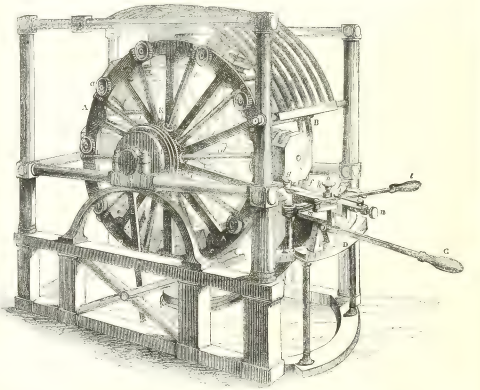


Fig. 153. THE SHAPING MACHINE

This machine is surrounded by an iron cage (a portion of which is shown in Fig. 153), for the purpose of defending the workmen, lest the blocks which are revolving with great velocity should be loosened by the action of the tool, and fly out by their centrifugal force.

9. As the blocks come from the shaping engine, they are taken to the *scoring engine*, which forms the groove round their longest diameters for the reception of their ropes or straps. This engine receives two blocks A, B, Fig. 154, each held between two small pillars, *a*, fixed in a strong plate D, and pressed against the pillars by a screw *b*, which acts on a clamp *d*. Over the blocks a pair of circular planes or cutters, E E, are fixed on one spindle, which is turned by a pulley in the middle. This spindle is fitted in a frame F F, moving in centres at *c c*, so as to rise and fall when moved by a handle *f*. This brings the cutters down upon the blocks, and the depth to which they can cut is regulated by a curved shape *g*, fixed by screws upon the plate D between the blocks. Upon this rests a curved piece of metal, *h*, fixed to the frame F, and enclosing, but not touching the pulley. To admit the cutters to traverse the whole length of the blocks, the plate *d* is sustained between the points of two centres, which are furnished with screws at *l*. On depressing the handle L, the frame is inclined. At M a lever, weighted at the end, counterbalances the weight of the blocks and plate D, all which are above the centre on which they move. The frame F has also a counterpoise to balance the cutters, &c. The cutters E are circular wheels of brass with round edges; each has two notches in its circumference at opposite sides, and, in these notches, chisels, fixed by screws, project beyond the rim of the wheel.

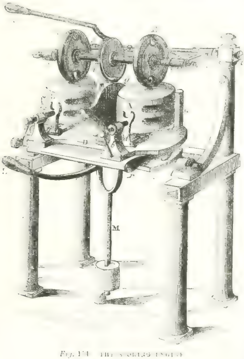


Fig. 154. THE SCORING ENGINE.

In using this machine, the block is pressed between the two pins, *e*, and the clamp *d* is screwed up against it. This clamp has two claws, each furnished with a ring, which enters the double points before mentioned in the end of the block. The blocks being properly mounted, the attendant presses the cutters E E by means of the handle *f* down upon the blocks, depressing them between their pins until their descent is stopped by the piece *h* resting on the shape *g*. He then turns the screws *b b*, to fix the blocks tight, and the cutters being put in motion will cut the scores, which, by the adjustment previously made, will be of no depth at the pin-hole; but, by depressing the handle L so as to incline the blocks, and keeping the cutters down upon their shape *g* by the handle *f*, they will cut any depth towards the ends of the blocks which the shape *g* admits. In this way one quarter of the score is formed; the other is done by turning both blocks together half round, by the following contrivance:—The centres *l* are not fitted into the plate D, but into a frame at K beneath the plate, which is connected with it by a centre pin exactly midway between the two blocks, A, B. A spring catch, the end of which is seen at *i*, confines them together; when the catch is pressed back, the plate D can be turned half round on its centre pin so as to change the blocks end for end, and bring the unscored quarters of those over the clamp beneath the cutters; the workman, taking the handles *f* and L one in each hand, and pressing them down, cuts out the second quarter. This might have been done by simply lifting up the handle L, in which case, however, the cutter would have struck against the grain of the wood, but by reversing the blocks, it always cuts clean and smooth in the direction of the grain. The third and fourth quarters of the score are cut by turning the other sides of the blocks upwards and repeating the above operations. The shape *g* can be shifted for different sizes and curves of blocks.

As some of the shaping machines cut the wood without reference to the grain, roughnesses are left which require to be smoothed down. This is done by hand, and a smooth polished surface is produced without removing any of the wood.

10. For making the sheaves, the first process is cutting pieces or flakes off the end of the trees of lignum vitae, of the proper thickness to form the sheaves. This is done by means of three *converting machines*, one with a reciprocating saw and the others with circular saws. The flakes are made circular, and their centres pierced by means of a *crown saw* which has a centrebit in the axis. The flake being fixed before this saw, it quickly cuts out a circle, and, at the same time, forms a centre hole.

11. *The coaking engine* is a most ingenious machine; it forms a cavity in the centre of the sheave for the reception of the coak or bush of bell-metal, which forms a socket for the centre pin. This cavity is in the form of three small semicircles, arranged at almost equal intervals round the hole formed by the last machine.

12. A *drilling machine* for perforating the three semicircular projections of the coaks, for the reception of short wire pins or rivets, which are rivetted down at the same time with the rest of the coak.

13. *Riveting hammers;* two small tilt hammers for [illegible] riveting the coaks after they are put into their places.

14. The centre holes through the coaks are next enlarged out to a true cylinder by means of the *broaching engine.*

15. The faces of the sheaves are lastly turned to a flat surface in a *facing lathe,* which also forms the groove in their periphery for receiving the rope. This completes the machine for making the sheaves.

The iron pin or axis of the block is forged by two smiths between two swages, or tools each having a semicircular cavity in it, so that the two when put together form a cylinder. The heated iron being laid in one of these, the iron is put over it and beaten with a hammer into a cylindrical form. One end of the pin is left square for a short length. In this state the pins are turned by a slide rest in the pin-turning lathe; this covers them with spiral scratches from the scorings of the tool, and they are afterwards polished and made perfect in the *polishing engine,* in which the [illegible] end of a vertical revolving axis, and forced down into a sort of die immersed in oil between the pieces of hard steel, between which the pin is pressed as it turns, and this perfects the polish.

Blocks, from 4 to 7 inches in length, are generally fitted with wooden pins, which are turned in a lathe called a [illegible].

There are also two machines for making dead-eyes from 5 to 9 inches, and also from 10 to 19 inches in diameter.

There is also a large *boring* machine, for making the largest sizes of blocks, called *made* blocks, some of which are as much as 4½ feet in length, with four sheaves.

The number of machines employed in making the blocks is forty-four. These are divided into three sets, so that three sets of blocks of different sizes may be proceeding in all their stages at the same time, although in some of these stages one machine operates at the same time upon two, or even ten blocks.

The different blocks made by these machines are as follows:—

Thick blocks, four varieties—single sheaves, double sheaves, treble, and fourfold. The sizes of each variety are from 4 inches to 28 inches in length; but only the first three varieties are made wholly by the machine, the fourfold being chiefly made by hand; but their sheaves and pins are entirely formed by the machine.

These make about	72	sizes
Thin blocks are the same as the above, but with narrow sheaves: these are from 6 to 26 inches in length . .	18	..
Clue-garnet and clue-line blocks, of peculiar construction, introduced by the inventor of this machinery .	[illegible]	..
Sister blocks	[illegible]	..
Top-sail sheet blocks	[illegible]	..
Fiddle or viol blocks	[illegible]	..
Jack blocks	[illegible]	..
	[illegible]	

The number of block-shells, of different sizes, made by each set of machines in a day, is thus stated:—

The first set of machines makes blocks, from 4 to 7 inches in length, at the rate of 700 per day. These have wooden pins.

The second set makes blocks, from 8 to 10 inches in length, with iron pins, at the rate of 520 per day.

The third set makes blocks, from 11 to 18 inches in length, with iron pins, at the rate of 200 per day. Total, 1,420 per day. [See APPENDIX.]

BLOOD is the general circulating fluid of the animal body, the source of nutriment and growth, and the material from which all the secretions are derived. In all vertebrated animals it is of two kinds, the *arterial,* which is of a bright red colour, and the *venous,* which is blackish purple. The temperature of the blood is connected with the degree of activity of the respiratory process. In man this temperature is about 98°. The density of blood varies from 1.053 to 1.057. It has a slimy feel, an alkaline reaction, and when recent, a peculiar odour. By the addition of sulphuric acid to old blood, an odour is developed, which is said to be characteristic of the animal from which it was obtained. Soon after blood has been drawn from its vessels, it gelatinizes or coagulates, and the jelly or coagulum separates into two parts, a liquid serum, and a solid clot or *crassamentum.* During coagulation, the colouring matter, called *hematosine,* which is diffused through the crassamentum, so as to give it a uniform red colour, is thrown off. This red pigment has many of the characters of a dye stuff, and contains oxide of iron.

The serum, or fluid part of blood, is an alkaline solution of albumen, containing various soluble salts. The clot is a mechanical mixture of fibrine and colouring matter, swollen and distended with serum. Blood is sometimes used in the arts for the sake of its albumen [See ALBUMEN]: but its use is much less at present than formerly. The chief use of blood is as a manure. It is seldom applied directly to the land, but is made up into a compost by mixing about 50 gallons of blood with a quarter of peat ashes and charcoal powder, and allowing the mixture to stand for a year or two. On light soils this compost raises excellent turnips, when applied alone at the rate of 48 bushels per imperial acre; or of 2 quarters, with 12 tons of farm-yard dung. As a top dressing to young wheat, 20 or 30 bushels an acre greatly increase the crop. In Northamptonshire, where this manure is much used, the blood is contracted for at the rate of 3*d.* a gallon. In some countries the blood is dried, and applied in the state of powder as a top dressing to the growing crops. In this state it is sold in Paris at about 8*s.* a cwt.[1]

BLOWPIPE, an instrument for directing a small jet of air laterally into the flame of a candle or lamp, whereby a portion of the flame is formed into a long slender cone in the direction of the jet, the heat of which increases towards the end of the cone, and at the point is most intense. In this way a common flame is converted into a species of furnace, capable

[1] "Johnston's Elements of Agricultural Chemistry," 1848.

of fusing or raising to a high degree of temperature any substance minute enough to be involved by the flame. The blowpipe is in common use in the Arts; it is used in soldering by the jeweller, goldsmith, and those who fabricate small objects in metal; by the glass-blower in making instruments and toys of glass; by the enameller, and others. It is also an invaluable instrument in the hands of the analytical chemist, superseding to a great extent the large furnaces and cumbrous apparatus of former times.

The common blowpipe, Fig. 155, is a conical tube or pipe, generally of brass, about 8 inches long, and a quarter of an inch diameter at the top, with a curvature near the lower end, whence it tapers off to a point, which has a very small perforation for the escape of the jet. This is the simplest and cheapest form, and is used at the present day by artisans. But as in using this tube the moisture of the breath is apt to condense within it, a bulb *b* is sometimes made near the small end of the pipe, as in Fig. 156; and to render it more portable, it is divided through the middle, and the two parts screw together when used. This form was improved by Bergman, and afterwards by Gahn, whose blowpipe consists of four pieces, *a, b, c, d*, Fig. 157.

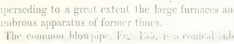


Fig. 155.

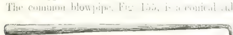


Fig. 156.

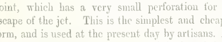


Fig. 157.

The small jet *d* is fitted by grinding to the extremity of the beak *c*, and several of these jets are provided with holes of different diameters, to be changed according as a larger and more moderate, or a smaller and more intense flame is required. The chamber *b*, for condensing the moisture, is a cylinder 1 inch long, and half-an-inch diameter. The varieties of blowpipe are very numerous. Wollaston's is the most portable. Figs. 158, 159, 160, show its form, the number of pieces composing it, and the method of putting the parts together, either for use or for travelling; *a, b, c*, Fig. 158, show the three pieces put together for use.

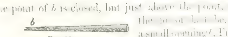


Fig. 158.

The point of *b* is closed, but just above the point, at the end of the tube, is a small opening *d*, Fig. 159, which emits the air into the beak *c*, Fig. 158, when brought into its proper situation on the tube. Fig. 160 represents the blowpipe packed up into the space of a pencil-case. "If we add to this a slip of platinum foil two or three inches long, to hold the object of experiment to the flame, and a small piece of borax to serve as a flux, we are furnished at once with a sufficient laboratory for a great variety of experiments; for the candle and charcoal may be found in most places." Fig. 161 is Pepys's blowpipe, in which the vapour is condensed in a flat cylindrical box, which also answers the purpose of holding additional caps for the nozzle. Fig. 162 is Dr. Black's blowpipe. It is of tinned iron; the small pipe *a* is of brass, and has two or three caps that fit on tight, each cap being pierced with a hole of a different diameter.

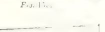


Fig. 159.

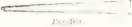


Fig. 160.

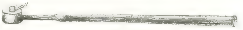


Fig. 161.

Fig. 162.

To use the blowpipe properly, requires some art, for while the air is inspired through the nostrils, that which is contained in the mouth must be forced out through the tube by the compression of the cheeks, so as to keep up a continued stream for a quarter of an hour if necessary. To acquire this art, Mr. Griffin advises the learner to begin by practising breathing through the nostrils with the mouth closed; then "let the learner transfer the air into his mouth, allowing his cheeks to distend as the air arrives through the posterior nostrils, and then let him make two or three moderate inspirations and expirations by the nostrils without opening the lips or suffering the air to escape from the mouth." Then "let him introduce between his lips the mouthpiece of a blowpipe, having a small aperture, and then, having filled his mouth with air, let him allow the same to be gently expelled through the tube by the action of the muscles of the cheeks, at the same time that he continues breathing, without interruption, through the nostrils. This is done by applying the tongue to the roof of the mouth, so as to interrupt the communication between the anterior part of the mouth, and the passage to the nostrils. When the mouth begins to be empty, it is replenished by the lungs in an instant, while the tongue is withdrawn from the roof of the mouth, and replaced again in the same manner as in pronouncing the monosyllable *tut*. After practising this for a few days, the muscles employed will be accustomed to this new exertion, and unless the flame be urged too impetuously, a continued current may be produced without any extraordinary exhaustion."

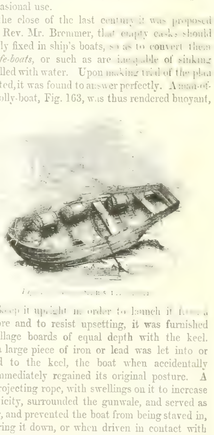
For the information which is to be acquired from the use of the blowpipe, we must refer to special treatises on the subject. One of the best of these is by Berzelius, a translation of which, from the French edition, was published by Mr. Children, in 1822. An American edition by Mr Whitney has been published more recently. Mr Griffin's "Practical Treatise on the use of the Blowpipe in Chemical and Mineral Analysis," Glasgow, 1827, is an admirable little work, a new edition of which would be of great assistance to the student. But the most elaborate Treatise on the Blowpipe is that by Professor Plattner, of Freiberg, entitled "Die Probirkunst mit dem Löthrohre," of which there is an English version by the author and Dr Muspratt, 1854.

The table blowpipe and other forms of compound blowpipe will be described under Enamel, Glass, &c.

BLUBBER, a deposit between the skin and the muscles of the members of the order Cetacea, and most abundant in the Greenland whale, its thickness being from 8 to 10 or 20 inches The uses of this layer are to render the huge body of these animals specifically lighter than the surrounding fluid; to assist in the preservation of the vital heat; and to afford protection to the internal organs against the effects of the enormous pressure to which these animals are subject in the depths of the ocean. The blubber of a full-grown whale is said to yield as much as 100 tuns of oil. It was formerly the custom, when whales were numerous, and the fishing comparatively easy, to boil the blubber on the spot, and to bring home the oil in casks. As the fishery became more difficult, and the whales had to be pursued further into the open sea, it was found more economical to bring home the blubber or *finks*, as it is called, cut in small pieces, and packed in casks. When it arrives in England, it is putrid, and in order to get rid of the rancid smell and taste, and to purify the oil, the following method is adopted. The casks are emptied into a large back, or receiver, containing about 20 tuns: from thence the fluid parts are suffered immediately to strain through a semi-circular wire grating in the side of the back, close to the bottom. This grating is about 4 feet wide, and 2 feet high, receding in a convex form into the back, and the wires sufficiently close to prevent the finks from passing through. The oil, as it drains through this grate, is conducted by a copper tube, 4 inches in diameter, into another back, containing about the same quantity. When this is full, it is left about two hours to settle, after which it is conducted by means of a sluice into a copper of the capacity of about 14 tuns, and is heated by a fire. The oil must be stirred in the copper until it has attained the temperature of 225°, which will destroy the rancidity of the smell, and also precipitate the grosser animal matters. As soon as this temperature is attained, the fire is removed, and about half a tun of cold water is pumped upon the surface of the oil in order to cool the bottom of the copper, and prevent the solid parts from adhering to the sides. The oil is then left to cool an hour, and is then drawn off into coolers, and when perfectly cold, is stored in casks. In this state it is fine, and fit for immediate use. [See Oil.]

BOAT. A small vessel, generally without a deck, managed by sails or oars, or drawn by horses upon canals. The form, equipment, and names of boats, vary according to the purpose for which they are intended; hence they are made slight or strong, sharp or flat-bottomed, open or decked, plain or ornamented, as they are designed for swiftness or burden, for deep or shallow water, for sailing in a harbour or a sea, and for convenience or pleasure. Boats are a necessary appendage to a ship: ships of the line have usually six boats, but the number decreases with the rate of the ship. The largest is called the *long-boat* or *launch*, and its chief use is to convey heavy stores to the ship. It is generally furnished with a mast and sails, and is sometimes decked, armed and equipped. Next in size to this is the *barge*, and its chief use is to convey the principal officers to or from the ship. It is of slender construction and of small breadth, and never rows less than ten oars. The *pinnace* is similar to the barge, but smaller: it never rows above eight oars, and is used by lieutenants in going ashore or coming off to the ship. *Cutters* are broader, deeper and shorter than the former; they are employed on most occasions for going ashore, carrying stores, provisions, boarding ships at sea, &c. The *jolly-boat* is the smallest boat used in any of the ships of the navy. In an East Indiaman there are four boats; the *long-boat* for conveying stores and goods to and from the ship; the *cutter* for going ashore; the *jolly-boat* and the *yawl* for occasional use.

At the close of the last century it was proposed by the Rev. Mr. Bremmer, that empty casks should be firmly fixed in ship's boats, so as to convert them into *life-boats*, or such as are incapable of sinking when filled with water. Upon making trial of the plan suggested, it was found to answer perfectly. A man-of-war's jolly-boat, Fig. 163, was thus rendered buoyant, and to keep it upright in order to launch it from a flat shore and to resist upsetting, it was furnished with billage boards of equal depth with the keel. When a large piece of iron or lead was let into or fastened to the keel, the boat when accidentally upset immediately regained its original posture. A stout projecting rope, with swellings on it to increase its elasticity, surrounded the gunwale, and served as a fender, and prevented the boat from being staved in, in lowering it down, or when driven in contact with the vessel it might be going to relieve. When this boat was filled with water and contained five persons, such was it buoyancy that it was kept above the water's edge, and could be rowed with the greatest ease, and was capable of performing any service required.


[illegible]

About the year 1785, Mr. Lukin took out a patent for a life-boat with projecting gunwales and hollow cases or double sides under them, as well as air-tight lockers or enclosures under the thwarts or seats for the rowers. These arrangements greatly increased the buoyancy, and prevented rolling. The great defect of this boat was its liability to be staved in. This led to the invention of a life-boat by Mr. Greathead of South Shields, in 1789, which was so successful in its operation that before the year 1804, it had saved nearly 300 lives from vessels wrecked near the mouth of the Tynemouth haven. The inventor received a gold medal and fifty guineas from the Society of Arts, and a parliamentary reward of 1,200*l.*, besides rewards from the Trinity House and Lloyd's Coffee-house. The success of this boat led to the establishment of stations at most of our ports, where life-boats, manned by active persons, were always kept ready to put to sea for the relief of seamen in distress. This boat, Fig. 164, was 30 feet in length and 10 feet in breadth, its greatest depth being about 3 feet, besides a general convexity which nearly doubled the depth as reckoned from the ends; the convexity below being intended to give it a greater facility of turning and a greater power of mounting on the waves without submersion of the bow, which would increase the resistance, although it would not sink the boat: the breadth was also continued further than usual fore and aft, in order to contribute to the same effect. The gunwale projected some inches, and the sides were cased and lined with cork secured by plates of copper and fastened with copper nails, which gave the boat so much buoyancy that it would float and be serviceable, although so much damaged as to be almost in pieces; but the cork by its softness and elasticity was well calculated to prevent such an accident. The whole quantity of cork was 7 cwt.: on the outside it was 4 inches thick, and extended the whole length of the shear or side of the boat: on the inside it was thicker. Ten short oars of fir were fixed on pins to the gunwales, and a longer oar for steering was fixed at each end, both ends of the boat being alike. The boat was painted white in order to be more conspicuous, and it was entrusted to an experienced man acquainted with the force and direction of tides and currents, and he was recommended to keep the boat with her head to the waves as much as possible, giving her an increased motion as she neared a wave. Much care is required on approaching the ship in distress, in consequence of the reflux of the waves, and it is in general better to get to the ship on the lee side. The rowers were recommended to exercise themselves in the use of this boat, and to obey strictly the person commanding. A carriage moving on four small wheels was provided for conveying this boat over land when required, but as this plan was not found very convenient, the following was adopted.—Two wheels 9 feet in diameter are connected by an arched axle, to which is fixed a strong pole of considerable length to serve as a lever: the wheels are so far apart that the boat can stand between them with the arched axle over its centre. When the pole is horizontal, the arch rises above the boat, but when the pole is erected perpendicularly, the arch touches the boat. In order to move the boat, the arched axle is brought over its centre and the pole set upright: two chains fastened to the arch are then hooked on to two eyebolts fixed in the inside of the boat: the pole is then lowered, the arch rises and brings up the boat with it. In this way it can be moved rapidly on land, and can be launched with great facility.

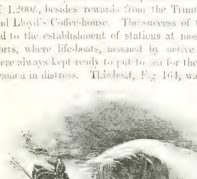


Fig. 164. [illegible]

In the year 1807, the gold medal of the Society of Arts was awarded to Mr. Christopher Wilson for a life-boat with air gunwales, which is said to be lighter and more manageable than Greathead's boat. One advantage of this boat was that the hollow cartridges or air vessels were distinct from each other, so that if one of them were beaten in by striking on a rock, the rest would still be serviceable.

Since the extensive application of India rubber, and more recently of gutta percha, to the purposes of the useful arts, these substances have been employed with much success in the construction of life-boats. Ships have also been furnished with various kinds of life buoys. [See BUOY.] Cork mattrasses have also been partially introduced on board ship, but as they afford facilities to the sailors to desert, they are discontinued. See LIFE-BOAT and APPENDIX.

BOBBIN-NET. See WEAVING, Sec. vi.

BOILER. See STEAM ENGINE.

BOILING. See EBULLITION.

BOLE. An earthy mineral forming one of the hydrous silicates of alumina, and resembling Soapstone. Specific gravity, 1.4 to 2. It occurs in masses in Armenia, Saxony, Italy, France, Ireland, Scotland, various parts of South America, &c. It is friable, has a greasy feel, and is of various colours, as yellow, brown, red, and black. When put into water it readily absorbs it, emitting bubbles of air, and falling to pieces. Bole found in the island of Lemnos, is called Lemnian earth, and was formerly employed as an astringent, absorbent, and tonic medicine, but this and the other varieties of bole have fallen into merited neglect as medicines. Any tonic effect they might have had was due to oxide of iron, which is now given in a purer form. Armenian bole is still in demand in India for this purpose, and boles in general still enter into veterinary medicines in Europe. Armenian bole is of a fine bright red, and is much used as a tooth-powder. Humboldt, in describing the habits of some savage nations of South America, says that they allay the pains of hunger by eating boles. Cakes made of these earths, and called *tanaampo*, are also in request among the natives of Java, when they wish to become thin. A coarse red bole calcined and levigated is sold in Germany as a pigment, under the name of Berlin and English Red.

BOMBAZINE (from the Greek *βόμβυξ*, a silkworm). A fabric of worsted and silk, the warp being of silk, and the weft or shoot of worsted.

BONE is formed of a dense cellular tissue of membranous matter, rendered stiff and rigid by insoluble earthy salts, of which phosphate of lime is the most abundant. The proportions of earthy and animal matter vary greatly with the kind of bone, and with the age of the individual, the bones of an adult being richer in earthy salts than those of an infant. The following comparative analysis of human and ox-bones will show the nature and amount of the constituents:—

	Human bones.	Ox bones.
Animal matter soluble by boiling	32.17	33.30
Vascular substance	1.13	
Phosphate of lime	53.04	57.35
Carbonate of lime	11.30	3.85
Phosphate of magnesia	1.16	2.05
Soda and a little common salt .	1.20	3.45
	100.00	100.00

The teeth have a similar composition, but contain less animal matter, so that their texture is more solid and compact than bones. The enamel does not contain more than 2 or 3 per cent. of animal matter.

If bone be digested in very dilute muriatic acid, a moderate degree of effervescence will take place in consequence of the presence of carbonate of lime. In some days all effervescence and chemical action will cease, and that which remains undissolved will still represent the size and form of the original bone, but its appearance is changed, for it is semi-transparent, cellular, soft, flexible, and to a certain extent elastic. If this be washed and boiled in water, a portion of it will dissolve, and the solution, boiled down to the proper consistence, will become viscid and gelatinous on cooling, and will dry into a hard glue. If again dissolved in water, it will become cloudy, and give a grey precipitate with solution of nutgalls, and exhibit all the properties of gelatine. The remaining portion is insoluble in water; it becomes hard and somewhat brittle in drying, and burns like horn. Dissolved in caustic fixed alkali, it forms a soapy liquor, and exhibits all the other properties of albumen or membrane. The acid solution in which the bone was steeped will on the addition of caustic ammonia give an abundant precipitate of phosphate of lime, and a much smaller precipitate of carbonate of lime on the addition of carbonate of ammonia.

Fat, although usually present in bone, is not an essential part thereof. The horn of the stag and of other animals of the same kind is entirely free from fat; hence, hartshorn jelly, made by boiling the shavings of stags'-horn in water, is often recommended to persons of very weak digestion in preference to other animal jellies, as being absolutely free from oil; for although hard fat will not combine with jelly, yet the softer oily fats will do so in small proportions.

All animals that eat flesh, also eat bones if of a size to be easily crushed and masticated. The richness of meat soups is increased by boiling the bones with the meat, but in this way only a small portion of the food contained in bones is made available; a part of the gelatine is with difficulty, and the membranous part not at all, soluble in common boiling water. Much of the fat locked up in the cells of the bone cannot escape unless the cells be broken into. The solid part of the long bones contains, however, very little soluble matter; but their enlarged extremities and articulating surfaces afford the chief supply of nutritive matter. These parts should be sawed off, and the rest broken to pieces. The bones of young animals thus treated will in the course of two or three hours yield most of their soluble matter to boiling water; but in the bones of the older animals the gelatine seems to be in a state of condensation approaching that in which it exists in the skin, and therefore requires the long-continued action of boiling water to separate it. By means of a *digester*, or boiler with a steam-tight cover and safety valve, the temperature of the water may be safely raised to 270° or 280°, but at a less heat than this the condensed gelatine and membranous portion of the bone become dissolved if previously reduced to small pieces. The insoluble residue will be found a friable, crumbling mass, with scarcely any remains of animal matter. Bone soups are prepared in this way at the hospitals and military head-quarters in France, and it has been proposed to make a collection of dry bones a part of the provisions of a garrison in case of siege. If formed into stacks covered with thatch, they would be imperishable, and not be exposed to the attacks of mice and rats. The only objection to bone soup is that it sometimes has a burnt flavour, but it has been proposed to get rid of this by first digesting the bones in dilute muriatic acid in a stone trough until the earthy matter is dissolved out; then wash the membranous portion now left in an abundance of water; and lastly, sprinkle it with a little soda to get rid of all traces of the acid. By exposure to the air the membranes will dry to a horny texture without any fear of decomposition; and this can be more easily converted into a palatable food than by cooking the entire bone.

In Norway and Sweden, in times of scarcity, fish-bones, such as those of the mackerel, browned on a gridiron until they become friable, and, eaten with pepper and salt, form a palatable food.

The spines in the back fin and tail of some fishes are used in some parts of the world for pointing arrows. The serrated teeth of sharks are also used as offensive weapons. Fish-hooks are made of bone by some nations; and bones of fine texture, especially the teeth or tusks of the hippopotamus, elephant, walrus, and narwhal, are well adapted for carving, sculpturing, and turning. Ivory is also used for inlaying. Common bone furnishes excellent handles for small brushes, and other articles. In making utensils of bone, the compact cylindrical ones are preferred, as being stronger, and admitting of a more uniform and higher polish. The scrapings, shavings, or saw-dust of bone fetch a good price in the market, as they are much used by pastry-cooks and others as a material for jelly, which they readily give out to boiling water. Bone shavings are also used in case-hardening small articles of steel.

Bones also form a valuable manure, and for this purpose a supply is often obtained from many of our limestones, which contain abundant remains of corals and other animals. In the Saurian remains that abound in lias limestone there is a large store of phosphate of lime, and many of the corallines contain as much of this valuable substance as the bones of mammalia. A large proportion of the bones collected in London are conveyed to different parts of the country, to be used as manure. The sloops and cutters from Hull take in their cargoes of bones above London Bridge. These are stowed in the hold in a more or less putrid state: here they ferment, and diffuse a putrid odour to a great distance; and when the cargo is discharged at Hull, they are frequently reeking and smoking from decomposition. This probably softens them, and allows them to be more easily crushed at the mill. Bones are also imported into Great Britain from South America and other parts, and some of the most celebrated battle-fields of our own time are also said to have furnished considerable supplies of this valuable commodity.

Professor Johnston remarks that, while 100lbs. of bone-dust add to the soil as much organic matter as [illegible] lbs. of horn, or [illegible] lbs. of blood or flesh, they add at the same time two-thirds of their weight of inorganic matter, consisting of lime, magnesia, soda, common salt, and phosphoric acid (in the phosphates), all of which must be present in a fertile soil, since the plants require a certain supply of them all at every period of their growth. These substances, like the inorganic matter of plants, may remain in the soil, and may exert a beneficial action upon vegetation after all the organic or gelatinous matter has decayed or disappeared. In order to bring the bones into a state in which the substances contained in them can be more readily taken up by the roots of plants, and at the same time be more uniformly distributed through the soil, the bone-dust is mixed with one-half its weight, and sometimes with its own weight, of sulphuric acid, diluted with from one to three times its bulk of water. After two or three days, with occasional stirring, the bones are entirely dissolved or reduced. The solution or paste may be dried up with charcoal-powder, with dried or charred peat, with sawdust, or with fine vegetable soil, and applied with the hand or with the drill to the turnip crop; or it may be diluted with fifty times its bulk of water, and be applied to the drills with a water-cart. This stimulates the young plants, and causes them to pass quickly through the first stages of their growth; [illegible] and the [illegible] of the earthy and saline elements, by which the [illegible] [illegible].

In many parts of the world bones are used as fuel. In the treeless steppes of Tartary, and in the pampas of South America, it is considered that the bones of an ox will produce heat enough for the cooking of its flesh.

Many poor people in London gain a scanty livelihood by collecting fragments of bone in the streets, which they sell to the manufacturers of sal-ammoniac. The dealers in marine stores also purchase bones, which they dispose of in a similar manner or to the soap-boilers. The bones thus collected are thrown into a cauldron of water, and boiled, for the purpose of clearing them of their fat, which is collected from the surface of the water, and used in the composition of soap.

The bones are then thrown into large retorts, and subjected to destructive distillation, the matter of the bone being resolved into its constituent elements from which new compounds are formed. Some of these pass off in vapour or gas, but the fixed principles remain in the retort. The volatile portions are carbonic acid and various combinations of hydrogen and carbon, forming different kinds of inflammable air, together with water, holding carbonate of ammonia in solution, and a peculiar oil, which is collected and afterwards employed to feed the lamps burning in small close chambers, the sides of which thus become covered with LAMP-BLACK. Towards the conclusion of the process, muriate of ammonia and sulphate of ammonia are formed, [illegible] the former (which is the sal-ammoniac, the great object of the manufacturer) is obtained by sublimation.

The mass remaining in the retorts consists of the earthy and saline portions of the bone, blackened by the carbon of the animal matter, in which state it is called *ivory black*, *bone black*, and *animal charcoal*. This substance has a remarkable attraction for organic colouring matter, and is largely used for removing the colouring matter from syrup in the refining of sugar, and in the purification of many other organic liquors. By exposing ivory black to an open fire, the carbon is driven off, and the bones are nearly blanched. These are reduced to powder, which is used for making the cupels of the assayer [See ASSAYING], also as a polishing powder for plate and other articles, and also by the manufacturers of phosphorus for making lucifer matches.

In the above process the inflammable gas might be collected, purified, and used for gas-lighting, in which case the only product thrown away would be the carbonic acid.

BOOKBINDING. The demand for books at the present period of our history, so greatly exceeding that of any former time, has had the effect of bringing together trades which before were scattered, and of supplying by machinery that which was formerly accomplished by manual skill and dexterity. This is the usual effect of a greatly increased demand, the conversion of trades and individual occupations into manufactures, and although the production of a book handsomely bound in cloth, with a figured or embossed cover, and gilt ornaments, and lettering, would seem to depend for its production more upon individual skill than upon large and complicated machinery, yet here, as in so many other cases, the manufacturer has, to a great extent, superseded the mechanic.

Nearly all the trades subsidiary to the production of a book have passed through similar mutations. The paper on which it is printed is no longer made by the slow and costly process of moulding or framing a sheet at a time, but is produced with wonderful rapidity by means of highly complex and ingenious machinery: the ink with which it is printed is made in vast quantities in factories specially devoted to that sole object: the boards which form its sides are a distinct object of manufacture; the cloth which covers it brings into play textile machinery, the most elaborate in the world: the printing press which works off the copies is specially adapted to the steam engine, which sets it in motion with admirable speed and precision. Had it not been for changes such as these, which belong almost to our own day, the thirst for knowledge, which now happily pervades all classes, could never have been allayed; education could not have diffused her blessings, and the best security for national peace and order would have been wanting. In all these cases, the machinery which has superseded hand labour in some directions has led to a vastly increased amount of hand labour and intelligence in other directions. There is now a greater demand than ever for type-founders and for compositors, for literary men and for artists; for engravers on wood and engravers on metal. And if in the binding of a book, the workshop has expanded into the factory, and if many of the manipulations of the binder are now superseded by machines, there are more folders, more sewers, nay, there are even more finishers than formerly existed; for the great demand for machine-bound books, so to speak, has led to a corresponding increase in the better descriptions of binding, which depend almost entirely on the taste and skill of the workman. The same principle is at work throughout the useful arts. A successful machine may supersede certain descriptions of hand labour, and cause for a time much privation and suffering, but it is sure to increase the demand for labour in other branches; a well ascertained fact which ought to be constantly borne in mind by the intelligent workman. He ought to seek every opportunity of acquiring skill in more than one department of his trade, so that should his services in one direction be superseded by a machine, he may be able to apply his skill in another.

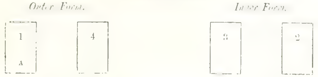
The effect of machinery upon the literary man has been, and is, in many respects highly beneficial. It is gradually raising his occupation into a profession, entailing the necessity of solid acquirements, an accurate style and business-like habits. He no longer writes under the uncertain favour of a patron, whose smiles must be purchased by the sacrifice of independence: he has now no occasion to dress like a man of fashion, or take charity in the shape of a humiliating "list of subscribers" to his work. The public is his patron, and his publisher his best friend.

Machinery has also had a marked effect in raising compositors into a highly intelligent and respectable class. It has increased their numbers and improved their efforts. Men who are constantly engaged in perpetuating information and intelligence must to a great extent become informed and intelligent. The compositor, the reader or corrector of the press, must be constantly assimilating some, at least, of the intellectual food which they assist in preparing for the world. Their labour can never be superseded by machinery, although machinery may greatly increase its extent and importance, and just in proportion as they become skilful and intelligent do they become valuable to the literary man with whom they are so intimately connected.

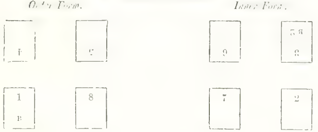
When the author and the compositor have accomplished their respective duties, the one in supplying "copy," and the other in "setting it up" in type, the manufacturing processes of a book may be said to begin. For the sake of convenience and economy, books are printed in sheets, the sizes of which are named according to the number and size of the pages in each sheet. The largest size is termed *folio*, (Latin *folium*, a leaf or sheet of paper;) the next size is *quarto*: then follow *octavo* or 8vo; *duodecimo* or 12mo, 16mo, 18mo, 24mo, 32mo, &c., which contain on one *form* or side of the sheet 2, 4, 8, 12, 16, 18, 24 and 32 pages respectively; but as all the sheets are *perfected*, that is, printed on both sides, these numbers must be doubled to give the actual number of pages in each sheet. Each of these sizes also admits of many varieties: thus, an octavo, although always consisting of 16 pages, may be *square octavo*, *royal octavo*, *super-royal octavo*, &c., which leads to very great complication.

The arrangement of the pages of one side of a sheet or of a form in their proper order, and the wedging them up in an iron frame called a *chase*, preparatory to their being printed, is called *imposing* a sheet, and as the sheet is to be printed on both sides, there are two forms to be imposed for every sheet, an *inner* and an *outer form*; the outer form containing the first page of the sheet or of the book, and all the other pages which, when the sheet is folded, fall in their proper order with the inner form, which contains the second or left-hand page of the sheet, and all the other pages which, when the sheet has been folded and cut open, fall also in their proper order. The following diagrams will serve to illustrate some of the most important sizes of sheets,

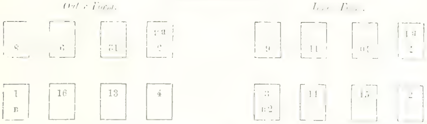
1. Sheet of Folio.



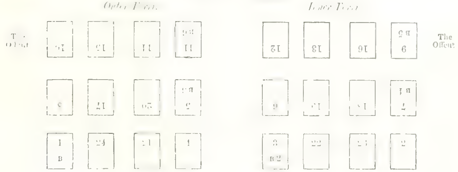
2. Sheet of Quarto.



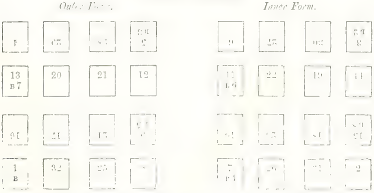
3. Sheet of Octavo.



4. Sheet of Twelves.



5. Sheet of Sixteens.



and the order in which the pages must be arranged in imposing the two forms of each sheet. It will be seen that by examining the *folios* or numbers of the pages of every two adjoining pages in a [illegible] their sum makes one more than the number of pages in the whole sheet: thus in a folio 1 + 4 = 5 are imposed together: in a quarto 1 + 8 = 9: in an octavo 1 + 16 = 17: in a duodecimo 1 + 24: in sixteens 1 + 32, in eighteens 1 + 36, and so on in every other size; this combination continues through all the other adjoining pages, according to the order in which they lie in the chase to be printed.

As a complete book or volume consists of a number of sheets, properly folded and following each other in the order of the folios or pages, it is necessary to have some distinguishing mark to each sheet for the convenience of the printer, the folder, and the binder. The numbers of the pages would be too slow and tedious for the purpose; their chief use being for the sake of convenient reference on the part of the reader. The printer, therefore, inserts at the bottom of the first page of every sheet, what he calls the *signature* of the sheet,[1] and this usually consists of the letters of the alphabet, the first sheet being usually marked B, (A being reserved for the title, contents, &c., which are usually printed last,) the second sheet is marked C, and so on throughout the letters of the old Roman alphabet, which did not contain the letters J V and W: these are therefore omitted. When this alphabet is exhausted, the twenty-third sheet is marked AA or 2A, the twenty-fourth BB or 2B, and so on to the end. The third alphabet is written AAA or 3A, and so on. It is also used for the purpose of guiding the printer in imposing and the folder in folding, to insert other minor signatures at the bottom of the third page of every sheet. Thus, if the signature of the first page of an octavo sheet be B, the signature at the bottom of the third page of the same sheet is B2, and in some cases the fifth and seventh pages are marked respectively, B3, B4. In some cases, especially in books printed in France and Germany, numbers instead of letters are used for the signatures. If the work be in two or more volumes, the number of the volume is added to each sheet, thus, VOL. II. B would be the signature of the first sheet of the second volume. In foreign books this signature would be simply II 1. In both cases the number of the volume is inserted at the left hand bottom corner, and the letter or numeral near the right hand bottom corner.

In imposing a sheet of twelves or duodecimo, eight pages in each form are arranged together in the manner of a small octavo sheet. Above these eight pages, with a wider space between, four pages are arranged in each form, forming what is called the *offcut*. In folding the sheet, these four pages are first cut off, and the remaining eight folded like a sheet of octavo. The offcut is then folded down the middle twice, and inserted within the fold of the sixteen pages, thus forming altogether the required number twenty-four. In a sheet of this kind the signatures are carried to B 6, B 5 being the first page of the offcut, and however numerous the pages may be in a sheet with one signature, if they are all inserted, they are continued to the last odd page before the middle of the sheet, but they are never carried beyond the middle. In strictness it is not necessary to insert more than the first two to indicate the first fold of the paper, and the first of the offcut. The others only disfigure the pages, and are not of much use to the folder, who has only to keep the signatures on the outside, and the pages must be folded correctly. In French books the first page of the offcut is often indicated by some small mark printed at the bottom, such as . .

No. 4 of the diagrams p. 153 is a sheet of twelves imposed with the first signature of the offcut in the inner form. By this arrangement it rises more conveniently for the folder, as it saves her the trouble of turning the offcut over every sheet. No. 5 is a sheet of sixteens to fold without cutting.

The sheets are delivered by the printer to the binder[2] in one of two arrangements. Suppose an edition of 1,000 copies of an 8vo work is to bound; the printer either delivers at once 1,000 copies of signature A, 1,000 of B, and so on to the end, or he causes them to be previously *gathered* into *quires;* that is, a single sheet of Z, supposing that to be the last sheet in the book, is taken, and upon this is placed a single sheet of Y; on this is placed a single sheet of X, and by proceeding in this way in a retrograde order, the gatherer at length arrives at B, the sheets being all in the proper order for folding. He then takes the title, contents &c., (signature A) and folding all the sheets together into a quire, lays them aside and proceeds to make up or gather a second quire, and so on till the whole 1,000 copies have been gathered.

The folding is performed at the binder's by females educated for the purpose. They are seated before a long flat board or bench, and each folder, placing the open quire of sheets before her, and with a folding-stick or paper-knife in her hand, folds the sheet in such a way that one page shall be exactly opposite to another in each sheet, taking care that the signatures shall fall properly. The folding is accomplished with remarkable precision and despatch, the result of long practice. A good folder will fold 500 octavo sheets per hour, but the usual average is about 300. In folding twelves with an offcut, the time occupied in folding is usually doubled.

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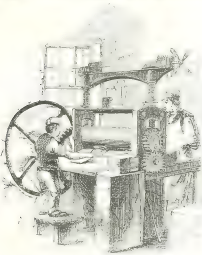
[1] There [illegible]. The catchword is the first [illegible] at the [illegible] purposes [illegible] and [illegible] used in modern printing.

[2] In preparing [illegible] to express his obligations to Messrs. [illegible] & Remnant, of [illegible] In this large [illegible] volumes per week are [illegible]

When the whole of the impression has been folded, the copies are knocked evenly together, and put into a hydrostatic press, for the purpose of compressing them into a compact form. If the work be newly printed, care must be taken not to press it [illegible]; as the fresh ink has a tendency to make an impression on the opposite page, as was generally the case with new books when compressed by the old method, which was to beat them on a large smooth stone with a cast-iron bell-shaped hammer weighing 12 or 14 lbs. This required some skill so as to compress or condense the sheets without marking them with the edge of the hammer, and to give the paper a smooth polished surface. This process was very much improved some years ago by Mr. Burn of Hatton Garden, who contrived a rolling press, Fig. 166, consisting of two iron cylinders, mounted and set in the usual way at any required distance apart. A number of sheets, varying from 6 to 14, according to the size, being placed between two tinned iron plates, are passed through the rollers. This method not only renders the paper smoother than by hammer-beating, but the compression of the book is $\frac{1}{6}$th greater, a very desirable object, inasmuch as the book-shelves will contain nearly $\frac{1}{6}$th more books. These superior effects are also produced by the rollers in $\frac{1}{20}$th of the time required by the hammer. This method is now adopted for books that have been printed some time, in which the ink is properly set, and also for books that require re-binding.

[illegible] DING.



After pressing, rolling, or hammering, each book is collated, to see that all the signatures run properly, and the plates (if any) are inserted in their proper places. The waste leaves are added at the beginning and end; the back and head are then knocked up square, and one side of the book is placed on a pressing-board of the size of the book itself, and another similar board is laid on the upper side of the book, taking care to let the back of the sheets project about half an inch between the two boards. The workman then grasps the boards firmly between the thumb and fingers of the left hand, and lowers them into the cutting-press, Fig. 167, which consists of two strong wooden cheeks *c c* connected by two iron bars *b b*, and two wooden screws *s s*. The use of the two guides on one of the cheeks will be explained hereafter, but it may be remarked that when these guides are not wanted, the press is turned completely over, so that these guides may be at the bottom, and out of the way. When the sheets are lowered between the cheeks *c c*, the press is screwed up tight by working an iron bar in the heads of the screws. The man then passes a tenon saw across the back of the sheets, so as to make a number of grooves, according to the size of the book, for the reception of the cords or bands for holding the threads in the sewing, and also for securing the boards which are to form the side covers. The number of bands depends upon the style of binding or method of finishing the book; periodicals, such as the Quarterly or Edinburgh Review, and boarded books, or books bound in cloth, have only two bands. But in the better descriptions of binding, 32mos sometimes have three bands; 18mo, 12mo, 8vo, and two-leaf 4tos, have 4 bands; royal octavo and whole sheet 4tos, 5 bands, and folios from 5 to 7 bands. In addition to these grooves for the bands, a groove is also formed at each end for the *catch* or *kettle* stitch. Supposing a book with two bands is to be sewed, it is taken to the sewing-press, Fig 168,[1] which is

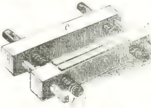


Fig. 167

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[1] This press is arranged for three bands, but for the sake of simplicity the description refers to two bands.

stout flat board *b b* containing an upright screw *s* at each end supporting a top rail *r* which rises and falls

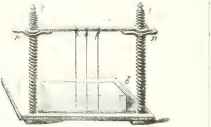
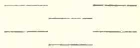


Fig. 168.

on the screws by means of nuts *n n*. Attached to this rail are several cords corresponding with the grooves sawed in the back, and these cords are secured by being fastened to brass keys, one of which is shown in Fig. 169, passed through the aperture in the bed of the press, while they are tightened by turning the nuts *n n*, so as to raise the top rail. The book to be sewn, being placed on the board *b* with the title uppermost, the sewer first takes the fly-leaf or end paper if such there be, or sheet A of the book, and turning it over so that the title page may lie with its face on the board, she places the grooves in it so as to correspond with the stretched strings or bands. She then passes the left hand into the opening of the sheet, and with the right pushes the needle through the right hand kettle-stitch; the left hand receives the needle and returns it out through the first groove above the stretched string; the right hand draws the needle completely through, and passes it through the same groove below the stretched string; the left hand takes the needle and passes it through the second groove above the string, and the right hand returns it below the second string; and lastly, the left hand returns the needle through the bottom kettle-stitch. The thread is then drawn so as to lie evenly in the angle of the sheet, a small piece being left projecting through the back at the top kettle-stitch. The sewer then takes the second sheet, and turning it over upon the first, inserts the stretched strings into the sawed grooves at the back. She passes the needle through the bottom kettle-stitch, and proceeds as before, passing the needle in and out round the bands, only proceeding up the sheet instead of down. When the needle comes out through the top kettle-stitch, the thread is drawn tight and secured by tying it into a knot with the end projecting from the first sheet. These two sheets form a sort of foundation for the subsequent sheets, which require a less elaborate sewing. Two sheets are taken at a time, and the thread is drawn through the grooves of each alternately. Passing the needle through the top kettle-stitch of the lower sheet, then out above the first band; then into the upper sheet below the first band; then out above the second band; then below this band into the lower sheet; then out through the kettle-stitch of the lower sheet; and lastly, this lower sheet is secured to the previous sheet by passing the thread round its lower kettle-stitch. Two more sheets are then taken, and in this way the sewing is continued with great rapidity. When one length of thread is nearly exhausted, another is taken, and joined to the former by a knot. This kind of sewing is called *up and down work*, and presents the following arrangement in the sheets of the book,—

Fig. 169.



the sheets showing two threads and one thread alternately, as the reader will find by examining any boarded book, or a book bound in cloth. When the sewing of one book is completed, the thread is secured at the kettle-stitch, and cut off. A second book is sewed upon the first, upon the same bands, until the press is full. The bands are then loosened by slipping off the keys, and the books are separated from each other by severing the bands, care being taken, for some descriptions of binding, to be noticed hereafter, to leave a sufficient portion of the bands projecting on each side of each book for the purpose of securing the boards.

There are various kinds of sewing, depending on the size of the book and the style of the binding

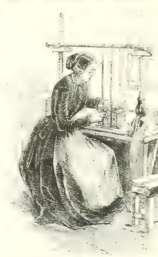
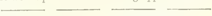


Fig. 170.—Sewing.

The commonest kind of sewing, such as we have attempted to describe, is called *sewing two sheets*, or *up and down work*. In some kinds of fine binding the sheets are sewed *all along*, and only one at a time; that is, the thread is passed round every band, so that supposing there were three bands, the sewing in every sheet would present the following appearance:—



Where it is an object to compress the book into the smallest possible compass, fine silk is used instead of thread, as occupying less space. To prevent injury to the book by sawing grooves for the bands, which cause the book to wear out much faster, (for the holes thus made gradually enlarge in size until the book falls to pieces,) a method of sewing is adopted without any grooves, tapes being used instead of strings. The only holes made in the sheets by this method are those of the needle, which is passed in and out above and below the tapes, and the sewer forms her own kettle-stitch with the needle. This kind of sewing is shown in Fig. 170. It requires more care than the former to keep the sheets even, and when well done the effect is excellent, for by this plan the book opens flat at any part, the fold of the sheet starting up fully to view when the book is opened.

When the books are folded and sewed, they pass from the female to the male department of the establishment. The first thing that is done is to secure the sewing by brushing a layer of glue over the back of each book, and covering the glue with a shred of paper or coarse thin canvass cut to the size of the back. If the book is to be boarded or bound in cloth, canvass is used of the same length as the back, but about half or three-quarters of an inch wider on each side, the projecting pieces serving to secure the side boards, as will be noticed presently. When the glue is dry, the book is laid flat between a couple of boards, and the projecting side and bottom edges are cut off tolerably true with a large knife kept sharp by frequent whetting on a dry stone. The folds of the sheets are not cut through; the only object of this trimming being to give the book a neat appearance. Then comes the operation of rounding the back, which is done by placing the book on its flat surface, and drawing the back on one side, gently tapping it with a broad-faced hammer: the book is then turned over upon its other surface, and the operation repeated, by which means the back is brought into a convex form. Each book is then placed separately between a couple of boards, with the back projecting, and is thus lowered into a screw press, which is screwed up tight. The workman then, by a succession of blows, applied somewhat obliquely up and down one side of the back, depresses that side, and causes a ridge to project over the board. He then repeats the operation on the other side, by which means the back is depressed at the two sides, and is raised in the middle; a few gentle taps in the middle and some finishing blows at the sides complete the rounding, and its effect is to form the side edges into a concave groove, the concavity of which corresponds with the convexity of the back, and the grooves formed at the two boundary lines of the back allow the boards or side covers of the book to fall in so as to present an even surface at the sides.

The books are now to be placed in thin cases, and the outside fly-leaf being pasted to the boards, the books are built up between wooden boards, the backs of the books outwards, and projecting; and this pile is placed in what is called a *standing press*, (Fig. 171,) consisting of a well-oiled iron screw working in a nut, and the upper bed of the press is screwed down with great force by means of an iron bar inserted into the inverted head of the screw. To economise labour, the pile, which constantly varies in size, is made to rest upon a number of boards, which diminishes the distance between the upper and lower beds of the press. There the books are left for some hours to undergo the requisite compression.

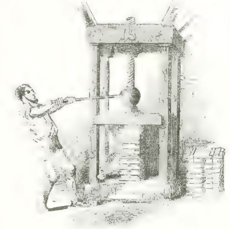


Fig. 171.—STANDING PRESS.

The mill-boards which form the solid substance of the covers are supplied to the binder in sheets, varying in size from 17½ inches by 11½, for the smaller sizes, up to 44 by 31 inches. The binder cuts up these sheets to the required size with great precision and rapidity, by a machine (Fig. 172) constructed for the purpose. It consists of an iron frame, one half of which

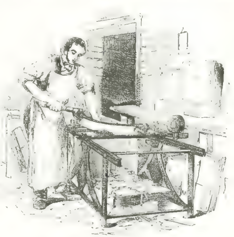


Fig. 172.—BOARD [illegible] MACHINE.

is covered with a horizontal plate, or table, for holding the board. At the inner edge of this table is a holdfast, or bar of metal, extending across the frame, moving on a hinge at the opposite side, and connected by a hinged lever on the near side with a treadle. The lower surface of this bar is furnished with file teeth, for holding the board fast. Just beyond this holdfast is a straight, fixed bar, with a square cutting edge, and by the side of this is a curved bar, or knife, mounted on an axis, and balanced by a weight at the further side, and furnished with a handle at the near side. The edge of this curved bar forms, with the fixed bar, a pair of shears, for cutting the boards. The gauge being set at the proper distance, the board is placed flat on the table, and its rough edge is first cut off. This is done by sliding the board along until the edge just projects beyond the shears. The man then puts his foot on the treadle, which brings the holdfast down, and secures the board; he next forces the curved blade down against the fixed blade, which cuts the board to a clean, smooth edge. Then, releasing the board, by lifting his foot off the treadle, and raising the knife, he passes the board up to the gauge, which is furnished with an edge or chamfer, and stops its farther progress: the board is cut through as before, the piece falling into the bin beneath. In this way the board is cut up into three or four long strips, the other long edge, nearer the left hand, being cut off while it rests on the table. A number of boards being thus cut up, each strip being sufficient for two, three, four, or more boards, the strips are again passed through the shears, and cut to the proper size of the books they are intended to cover. Such is the precision of this machine, that when all the pieces thus cut are piled up and knocked together, they appear to form a solid parallelopipedon, with perfectly sharp edges, in consequence of all the pieces being of the same size.

The cover of the book may be of leather or of cloth; but in either case it is ornamented at the back and sides with a pattern enclosed within a figured or flowered border, with different toolings and devices for the back, and blank borders for the gold lettering, or other ornaments. These are stamped, by means of certain presses, varying in power, with the material to be embossed. The largest press which is used for embossing leather, is a ponderous fly press, Fig. 174, situated in the cellar of the establishment. It consists of a solid iron frame, resting on a brick foundation, and well secured by iron ties. The lower bed of the press (also of iron) is perforated with two openings, into which a gas-pipe, formed like a fork with two prongs, and connected with a flexible tube, is inserted, for the purpose of heating the lower bed, upon which the metal die containing the pattern is placed, and by this means the die is kept at a tolerably steady high temperature, which is found most favourable for embossing. The dies are formed either of steel or brass, the latter being the more common. The dies are cut or chased by hand; but, for some patterns, consisting of regular curves, they can be more economically turned in the lathe, in which case brass must be used. The counter die, which is attached to the upper bed of the press, is formed by the man who manages the press, by glueing a number of pieces of millboard together, and glueing them to the surface of the upper bed. By swinging the arms of the press round, the lower surface of the millboard is brought down with immense force upon the metal die, and the softer material takes the impression of the harder. The man then cuts and trims and adjusts the counter die, every now and then taking impressions on paper; and when he is satisfied with his arrangement, he proceeds to emboss the leather pieces cut to the proper size for covering the book. In order that he may place the leather evenly in the press, so as to receive the impression in the exact spot required, the lower die is furnished with a millboard collar (Fig. 173), so that all he has to do is to place the leather, face downwards, on the square, or whatever figure it may be, which is the exact size of the leather, making the two upper corners of the leather coincide with the corners *a b* of the collar. This being done, the embosser, who is seated in a pit before the frame, directs the man on the floor above to work the press. This man swings round the ponderous arm, furnished with two huge balls at its extremities, and by the weight as well as the centrifugal force of this arm, the upper bed is jerked down upon the lower one, and the leather, in an instant, takes the impression of the die. Every piece of leather requires to be passed three times through the press,—once for the back, which is, of course, of a different pattern to the sides, and once for each of the sides. If the two sides are of the same pattern, the man embosses all the leathers on one side,—say the left,—and, in order to save the necessity of turning round and re-adjusting the die, he carries the leathers to the other side of the press, and then works all the right hand sides.

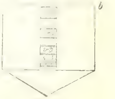


Fig. 173.

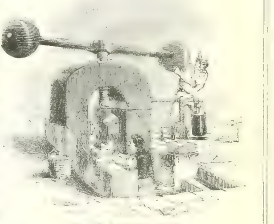
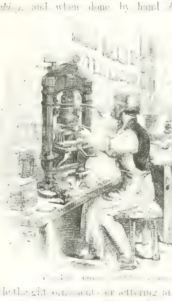


FIG. 174.—EMBOSSING PRESS.

Cloth covers are embossed after the boards are inserted. The cloth which is now consumed in such enormous quantities in bookbinding, is manufactured for the purpose in Manchester, and is sent up to the London dealers in the article, who dye it of various colours, and glaze or calender it, and send it to the binders in rolls or pieces, each forty yards long and thirty-six inches wide. The cloth is cut up to the proper size of the cover, an extra quantity being allowed for the overlap ping in the boards. The cases are then made up, with great rapidity, by two men, one of whom covers the inside with a layer of glue; then places two mill-boards in their proper position on the cover, so as to form the stiff sides, the space between the two depending, of course, on the thickness of the book. He then turns the cover over, and rubs the cloth firmly down with a cloth rubber shaped something like the stone muller used in colour-grinding. He then tosses the cover to a man, who places a strip of paper or canvass along the inside of the back between the two boards, and then folds down the projecting edges of the cloth over the boards, smoothing them down with the edge of a flat piece of stick with a blunt point at each end, and then drawing the point of the stick down the boundary lines between the back and the sides. The two men complete about 100 covers in an hour.

When the covers thus formed are perfectly dry, they are embossed and gilt. The ornaments which are simply produced by pressure are called *blocking*, and when done by hand *blind-tooling*;



[illegible]

while the gilt ornaments or letterings are called *gold blocking* or *gold-tooling*. The machines employed in both descriptions of ornament are called *blocking-presses*, and they do not greatly differ except in power from the fly-press already described. The ornamental pattern for the back or sides is cut out in a thick plate or block of brass, and is fixed in the upper bed of the press by means of a dovetail joint. This upper bed is furnished with a cavity containing a gas-pipe with a row of jets for heating the die by conduction of heat from the upper bed. The cloth covers are inserted within metal rules, which serve as a gauge, by a man who stands before the press, while another man swings round with all his strength a long lever, whereby the upper bed is brought down a few inches upon the case in the lower bed, and embosses the impression. When the cases are completed in this way, they are taken to the gilder, who cover the parts intended to be gilt with a thin layer of ovalbumen or white of egg, called *glaire*, and then with a film of leaf-gold. [See GILDING.] The covers are then passed to a gold-blocking press, (Fig. 175,) containing a plate or block, in which are set up the lettering and other ornaments intended to be gilt. The letters may either be set up in movable type, or cut out of one solid piece of brass. For the ornaments, the latter course is adopted. The block is heated by jets of gas playing in a cavity of the upper bed, and the cover being carefully introduced into a gauged bed, the man moves a handle round, which brings the heated plate with a gentle and equable pressure down upon the cover, and permanently fixes the letters or device. As the covers are removed, they are taken by a boy, who wipes off the superfluous gold with a piece of thick rag, which thus gradually absorbs the fragile leaf, and in the course of two or three months this rag is so valuable that it is sold for perhaps 20*s*. or 30*s*. to the gold refiner, who burns it in a covered crucible, and thus recovers the precious metal.

The covers thus formed are next adjusted to the books, which we left in the standing-press. The covers are secured to the books by glueing the canvass strips which project on each side of the back to the boards, and to conceal this arrangement as well as the uncovered parts of the boards, and also to give a neat finish to the book, some coloured paper called *lining paper* is glued in. The books are lastly put into the standing-press for a few hours, and may then be said to be finished.

We have thus traced the various processes concerned in binding a cloth-boarded book. They consist of gathering, folding, and sewing the sheets; glueing and rounding the backs; cutting the edges; making, embossing, and gilding the covers; and lastly, securing the covers to the books. In a large establishment, such as Messrs. Remnant's, the whole impression of an octavo work, consisting of 1,000 copies can be done up in cloth in the course of about six hours; in which case, however, the cloth covers are prepared a day or two before, all the information required for the purpose being the thickness of the book, which is known by stating the number of sheets contained in it. The title and the style of ornament, colour of the cloth, &c., are also determined. A thousand covers or cases can be prepared in one or two days. The book itself can be folded, stitched, glued, and rounded, the edges trimmed, and the book mounted in cases and pressed, all within six hours. This is indeed an extraordinary example of the power of numbers of skilful workpeople, and the effect of a refined system of division of labour.

The method of binding thus far described applies chiefly to those books which are issued in large numbers, and whether the covers be leather or cloth, there is no very great difference in the methods adopted. In leather bindings, such as in Bibles and Prayer Books, the edges, instead of being trimmed with a knife, as before described, are cut through with a *plough*, so that there is no necessity for cutting open the book before reading it. The bookbinder's plough consists of two upright cheeks of wood, *c c*, (Fig. 176,) connected together by a wooden screw *s*, and a couple of guides, *b b*, fixed into one cheek, and moving in square holes in the other. The screw passes through both cheeks, so that by turning it round in one direction the cheeks are brought nearer together, and in the contrary direction moved farther apart. Into one of the cheeks at *k* is fixed a cutting-knife, (Fig. 177,) a double-edged, pointed blade, of which two forms are given. The book to be ploughed is placed between a couple of boards in the press, with the edges projecting as much as is required, and one of the cheeks being placed in a groove of the press, the point of the knife is brought up to the book, and moved backwards and forwards against it, the workman at the same time giving the handle of the screw a twist, which advances the knife forward until the cutting is completed. (Fig. 178.) The white edges of the book in common binding are then *sprinkled*, whereby the speckled or mottled effect is given to them, which prevents them from soiling, and also improves the appearance of the book. This is done by mixing up some coloured chalk, umber, Venetian red, or ochre, in a little size and water, and dipping a brush into the mixture, so as just to wet the hairs; the man holds a long piece of wood a few feet over the books, and dashes the hairs of the brush against it, which causes a shower of minute drops of colour to rain down upon the edges of the books, a number of which are set up together for the purpose. When the desired effect is produced on the top edges, the books are turned over, and the bottom edges are treated in a similar manner, the man turning up one of the finished edges every now and then, to see that he is producing the same tint of colour at the bottom as at the top. The side edges are done in the same way, and the colour is fixed by placing the books in the bench press, and passing an agate burnisher over the edges, which produces a high polish, and prevents the colour from being removed by ordinary use. By these simple and expeditious processes a cheap and useful ornament is added to the books.

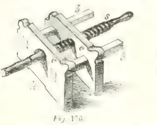


Fig. 176.

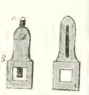


Fig. 177.

In the better class of binding, as in whole bound calf, gilt lettered, with raised backs, the boards are added after the glueing and rounding of the backs, for which purpose the sewer leaves small projecting pieces of string bands. The boards being cut to the proper size, a couple of holes are made in each board with a brad-awl, opposite each band, and the string being passed through these holes is secured with glue. In a book of three bands, the boards are held by six strings, three on each side, and each board is of course pierced with six holes. The books are then put into the standing-press for a few hours, after which the edges are ploughed, (Fig. 178,) the boards being slightly depressed below the edge to be cut off, the strings allowing them a little play before the cover is put on. In cutting the side edges, the workman takes care to preserve the concavity produced by the rounding, for which purpose he flattens the back by passing a flat tool between the edges of the boards, which are allowed to hang down loose, and the back. He then places the book between a couple of boards, grasps it tightly, and withdraws the flat tool; then lowers it into the press, and screws it up tightly. By thus flattening the back, the edges become flat also, and when they have been ploughed, and the book is taken out of the press, the back starts into shape again, and the side edges become concave. After this, the edges are gilt or marbled. In gilding, the book is secured between a couple of boards in the press, and the edges being covered with glaire, a layer of gold leaf is laid on, and the agate burnisher being well rubbed over every part across the edges, secures the gold leaf, at the same time giving it a beautiful polish. When all the edges are thus gilt, paper is wrapped round them, to prevent them from getting soiled. When the edges are to be marbled, the books are sent out to the marbler's, who produces the effect of marbled paper by the following contrivance. A trough about two inches deep is filled with clean gum-water. Various coloured pigments, ground in spirits of wine, and mixed with a small quantity of ox-gall, are thrown upon the surface of the gum-water, and disposed in various forms with a quill and comb, according to the desired pattern. This being obtained, the book is tied between two boards, and the edges being dipped into the trough, the floating colours become attached; cold water is then dashed over the edges, which sets the colours, and brings them out clear.

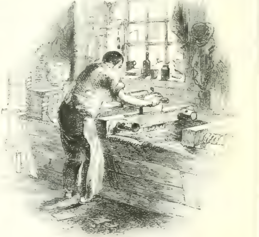
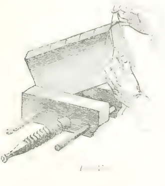


Fig. 178. [illegible]

The book is now ready to receive the *head-band*, which serves as a finish to the top and bottom of the [illegible] sheets, and as it [illegible] keeps [illegible] the upper [illegible] of the [illegible] shape, [illegible] The book, still in the rough boards, is fixed by [illegible] corner in a small portable screw-press, [illegible] Fig. 179, [illegible] back, is secured by passing a needle and thread [illegible] or three times between the leaves through the [illegible] [illegible] which is generally of silk or cotton, two or th[illegible] colours being sometimes used, is then twisted [illegible] plaited over the strip, and when about a third [illegible] one-half is covered, it is further secured by a few



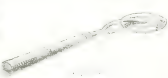
[illegible]

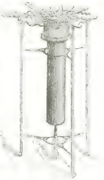
stitches through the solid back. The plaiting or covering [illegible] completed, and is secured [illegible] by sewing through the back The superfluous portions of the strip are then cut off. This description of head-band is called [illegible]; a [illegible] description, called *stuck-on*, is a piece of striped or coloured linen, enclosing a piece of cord, stuck or glued to the back of the book. The bands or raised projections at the back of the book are formed by gluing strips of mill-board, leather, or cord across them.

The book is now ready for covering. The leather may be calf, or morocco, or russia; but, whatever the leather, it is carefully chosen, so as to be free from blemishes, and of the proper size, and, being placed on a flat board, with the rough side up, the edges are pared thin with a sharp knife, so that in turning them over the board, they may not bulge out into unsightly projections. The leather is then damped, and covered with paste, and applied to the book, a few simple tools being used to smooth it down and press it into shape, to square the edges, and to raise the bands. The leather is neatly turned in at the top and bottom, and then folded over the head-bands. When the sides and edges [illegible] squared, the bands at the back are raised, and the spaces between them depressed, by [illegible] them with a bone paper-knife, and during all these manipulations the man every now and then moistens the leather with a bit of wet sponge. When the leather cover is properly arranged, the marbled or other lining papers are inserted, and the book is put into the standing press for a few hours, after which it is ready for tooling. But in some descriptions of binding, a good effect is produced by having distinct lettering pieces, of a different colour from the general [illegible] [illegible] the edges, and attached by means of glue. The blind-tool ornaments of the book are put on by means of pieces of brass, cut into the desired pattern and [illegible] Figs. 180, 181.

[illegible]

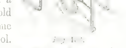
[illegible] long line, plain or figured, is to run up the sides of the book, it is cut upon the periphery of a disc of brass, Fig. 182, moving upon a central axis, and [illegible] which [illegible] [illegible] the [illegible] each side of the cover. All [illegible] heated at [illegible] unwholesome charcoal brazier formerly in use. The small tools are pressed down with an equable force in those parts [illegible] [illegible] the part thus covered. On wiping off the gold with a rag, that part of the gold only is attached which came in contact with the hot tool.





[illegible]

Lettering is performed commonly by a set of lettering tools, each letter of the alphabet being cut out in brass, and mounted in a wooden handle. Letters, numerals, &c., are kept of different sizes; but for words in common use, such as "Holy Bible," "Atlas," &c., tools are kept, with the whole word or words cut in them, as in Fig. 184. When the ornaments, lettering, &c., are complete, the book is finished off with polishing-irons, of various shapes and sizes, one of which is shown in Fig. 185. These are heated, and



[illegible] over [illegible] leather, and also over the marble [illegible] paper, &c.

We have thus gone over the principal processes concerned in binding a book. A few years ago, a method of binding by [illegible] glue are dispensed with, and instead of leaves attached by thread stitches at two or three points, they are agglutinated securely along their whole length. This plan is admirably adapted for binding engravings, maps, manuscripts, and collections of letters, which have little or no margin left at the back for the stitching. The plan has been thus described:—"After folding the sheets in double leaves, the workman places them vertically, with the edges forming the back of the book downwards, in a concave mould, of such rounded or semi-cylindrical shape as the back of the book is intended to have. The mould for this purpose consists of two parallel upright boards, set apart upon a cradle frame, each having a portion or portions cut out vertically, somewhat deeper than the breadth of the book, but of a width nearly equal to its thickness before it is pressed. One of these upright boards may be slidden nearer to or further from its fellow, by means of a guide-bar, attached to the sole of the cradle. Thus the distance between the concave bed of the two vertical slots in which the book rests may be varied according to the length of the leaves. In all cases about one-fourth of the length of the book at each end projects beyond the board, so that one-half rests between the two boards. Two or three packthreads are now bound round the leaves thus arranged, from top to bottom of the page, in different lines, in order to preserve the form given to the back of the mould in which it lay. The book is next subjected to the action of the press. The back, which is left projecting very slightly in front, is then smeared carefully by the fingers with a solution of caoutchouc, whereby each paper-edge receives a small portion of the cement. In a few hours it is sufficiently dry to take another coat of a somewhat stronger caoutchouc solution. In forty-eight hours four applications of the caoutchouc may be made and dried. The back and the adjoining part of the sides are next covered with the usual band or fillet of cloth, glued on with caoutchouc; after which the book is ready to have the boards attached, and to be covered with leather or parchment, as may be desired."

Vellum binding is a distinct branch of the trade, and is applied to the binding of every description of account-book. The paper is first folded and counted into sections, which in foolscap generally consist of six sheets, and above that size, of four sheets. These are sewed upon strips of vellum, three strips being usually applied to foolscap folio, and a greater number for larger sizes. In sewing account-books, waxed thread is used as being stronger. After sewing, the first ruled leaf at each end is pasted to the waste paper and the marble lining paper inserted. The back is then glued, and when dry, the fore edge is cut and the back rounded, a rounder back and consequently a deeper hollow being given than in printed books. The two ends are then cut and the edges marbled. The head-bands are worked on a slip of mill-board as before described. Strong pieces of canvass or buckram are then glued at the top and bottom of the back and between each of the vellum slips. A hollow back is produced by soaking in water a strip of mill-board about a quarter of an inch wider than the back of the book and gluing it on both sides; it is then placed on a sheet of paper, and a roller corresponding to the curvature of the back of the book is placed upon it, and the strip is worked backwards and forwards on the roller, which gives it the semicircular shape. It is then dried hard before the fire. Another method is to paste a number of pieces of paper in succession upon a roller, and when thoroughly dry it is cut down lengthwise, thus forming two semicircular backs. Thin sheet-iron is sometimes used for the purpose. The milled boards are then cut out for the side covers. In large books it is usual to glue together two thin boards for each cover, and to insert between them the projecting ends of the vellum bands on which the book is sewn. The first and last fly-leaves are pasted to the boards, and after they are squared, the curved back above described is placed on, and a piece of canvass sufficient to extend over half the width of the book on one side to the same distance on the other side, is glued on the boards and over the back: this holds the hollow back firmly in place. The book is then ready for covering, for which purpose the leather is carefully pared all round and neatly put on. The covers are usually forril and vellum, white and coloured; smooth and rough calf and sheep; basil, smooth and grained, and russia. Forril and vellum covers are lined with paper and pressed smooth. When dry, they are fitted on the back and creased in the joints: the boards are then pasted and the covers pressed on them: when dry, the edges of the cover are pasted and turned in and the book again pressed: the cover is then washed with a sponge and paste-water, and then ruled off. If the cover be rough calf or sheep, it is dressed with pumice-stone and a clothes-brush. Smooth calf, basil, &c., are glaired and polished as in bookbinding. Rough calf books are usually ornamented by passing a very hot roller round the edges and sides of the cover. Large books are sometimes furnished with bands of russia leather worked on with thongs of vellum, which add to the strength of the binding and have a neat appearance.

BORACIC ACID. BORAX. See BORON.

BORING may be regarded as a branch of TURNING; but in the former the tool is generally made to revolve while the work remains stationary, while in the latter the work revolves while the tool is stationary or nearly so. There are, however, exceptions to this, as in boring or forming the cylindrical cavity of ordnance both methods are adopted; in one, the gun revolves and the borer advances in a fixed axis, and by another method the gun is fixed and the cutter revolves. The former is adopted for brass guns, and as the gun revolves, its exterior surface is turned. Cannon are now always cast solid, and the cylindrical cavity is formed by boring into this solid mass. The gun is placed horizontally in the boring-mill, and is fixed to the axis of the mill by means of the square piece at the cascabel. In a boring-mill constructed by Smeaton, the gun is placed on the horizontal axis of a water-wheel, and consequently revolves with the same velocity. On this same axis, Fig. 186 is a toothed wheel which works two wheels,

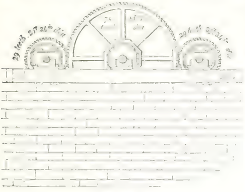


Fig. 186.

are placed on each side, and on the axis of each of these is a gun of smaller size. A bar of steel in shape and size like the coulter of a plough, is first applied at right angles to the axis of the gun. The narrow side of the bar is sharpened to a cutting edge, so as to have the form of one tooth of a very large saw, and this being opposed to the direction of the revolving motion of the gun, takes off an angular portion at right angles to the axis, until the cylindrical part connecting the head with the gun is so much diminished that the head falls off with the blow of a hammer. The boring is then commenced by exposing the revolving gun to the action of a steel cutter fixed to the end of a bar placed on a carriage and impelled continually towards the gun. The carriage, which slides in two parallel iron grooves, consists merely of a bar on which the rack is pressed forward by the pinion P, Fig. 187, whose gudgeons are on a fixed frame B B, and this pinion works into a rack R. The axis of the pinion has mortised holes in it, through which, one end of the lever L is passed, and the other end is loaded with a weight W, which causes the pinion to propel the carriage and thus urge the boring bar towards the gun. In some machines two pinions are attached to the same

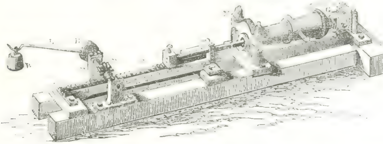


Fig. 187.—CANNON-BORING MACHINE.

axis and act on two racks. In other cases the carriage is propelled by two upright levers, the end of one of which has a weight hanging from a rope passing over a pulley: the lower end of the upper lever rests on the upper end of the lower, while the lower extremity of the lower lever presses forward the carriage. This method is free from any inequalities arising from the teeth of the rack. According to another contrivance, a screw acting on the end of the carriage is used to propel it. The boring bar used in all these machines is a very strong wrought-iron bar of less diameter than the calibre, in order to allow the iron dust and shavings to be readily got out; its diameter is increased for some inches near the end B, Fig. 188, where there is a groove for admitting the steel cutter T, the two upper angles of which are cut off obliquely so as to form an obtuse angled drill, the edges of which coming in contact with the revolving metal produce a conical cavity by taking off shavings from the solid metal. The first bore is smaller than the intended size. When this is completed, a second borer, consisting of a cross bit or rectangular piece of steel, with a cutting edge at each end, is put through a hole in the boring bar, and the edges of this cutter in revolving describe a cylindrical surface. When the bore is of the proper size and sufficiently true, a bit without a point and rounded off to the desired curve is used to form the bottom of the chamber. The cutters become magnetic in consequence of being continually rubbed in the same direction, and the boring dust is seen hanging from their edges when they are withdrawn. While the boring is being conducted in this way, the exterior of the gun is turned by appropriate turning tools. A wooden gauge or cut-out profile of the gun with its intended mouldings is applied from time to time to ascertain when the turning has been continued to the proper depth. The cyphers and arms cast on the gun are finished by a chisel. The touch-hole is drilled by stock and bit, or by drill and bow. The gun is then examined to ascertain whether the bore is free from holes: this is done with an instrument consisting of several elastic steel prongs with sharp points arranged in a circle: by moving this backwards and forwards in various ways, the points press against the side, and thus detect any hole that may exist. A lighted wax taper is also introduced, or the light of the sun is reflected by a mirror into the bore, by which means defects can be detected and examined by eye. The gun is proved by firing it with a large charge of powder, and also by forcing water into the bore

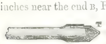


Fig. 188.

through a powerful force pump, the touch-hole being stopped. All these precautions in boring and ascertaining the accuracy of the bore have greatly contributed to the present precision in artillery practice.

The boring of muskets and small arms will be more conveniently described in connexion with the processes concerned in the manufacture of Gun Barrels.

The boring of cylinders for steam engines, blowing machines, working-barrels of large pumps, and other hollow cylinders of cast-iron in which pistons work, requires very powerful and accurate machinery. The cylinder is cast hollow, and the object of the boring machine is to convert the interior into a true cylinder. The machine shown in Fig. 189, was contrived at the time when accurately bored cylinders were required, in consequence of Watt's improvement in steam engines. In this arrangement the cylinder is placed horizontally, while the cutters revolve and advance by the action of some powerful prime mover, and the operation is commonly repeated three times, in the last of which the greatest care is required, and the engine is worked from the beginning to the end of the operation. This is also done, by some makers, in the finishing process of boring ordnance, the machine being kept at work through meal-times, day and night; for if it were discontinued while the cutter was only midway or in any part of its journey, and the cylinder allowed to lose the heat it acquires by the friction of the cutter, &c., a ridge and unevenness would be formed in the surface, which would greatly interfere with its proper action.

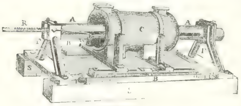
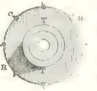


Fig. 189.

In the boring engine, Fig. 189, s s are two solid sills of oak, arranged parallel to each other and to sleepers let into the ground; at each end is a vertical iron frame, F F, for supporting gudgeons at the end of a long cylindrical axis or tube of cast-iron A A, which revolves by the prime mover. The cylinder C to be bored, is fixed over this bar on an adjusting framing B, and is supported by blocks below, and held fast by iron bands drawn down by screws in the top of standards. The cylinder is adjusted so as to be concentric with the axis A, and is held firmly by wedges driven under the blocks and standards. On this axis slides a cutter-head or piece of cast iron, R T, Fig. 190, into which are fixed cutters *c c*. The tube A, shown separately in Fig. 191, is divided by a longitudinal aperture *a* on each side, except at the ends, where it forms a complete tube to keep the two halves together. The cutter-head R T, Fig. 190, consists of a tube T, Fig. 191, accurately fitted on the axis A, and a cast-iron ring R fixed upon T by four wedges. On this circle are eight notches for the reception of the cutters. The slide R is kept from slipping round with the axis by two short iron bars *b b*, which are passed through the axis and received into notches cut in the ends of the sliders R, and a bolt passing through the holes in the middle of the sliders at the end of the toothed rack R; a key put through the end of the bolt prevents the rack from being drawn back, and holds the cross-bars *b b* in place. The rack is worked by the teeth of the pinion P, and is kept in place by the roller O. The axis of the pinion and roller is attached to the standard F, Fig. 189, and the pinion is turned round by the action of the weight W at the end of a lever on the square end of the axis. By another contrivance, four small wheels are fixed at the right hand of A, Fig. 192. Another pinion fixed to the extremity of the axis, similar to the rack R, has at its other extremity a small screw, which works an interior screw fixed to the cutters R at *b*. Below the second pinion is another fixed on a horizontal axis parallel to A. At the other end of the axis is a fourth pinion driven by the first at the end of the hollow axis A. As the axis A revolves, the first pinion at its extremity drives the fourth, which by means of the third, fixed on the same axis with it, gives motion to the second; the second pinion, being fixed on an axis within F, unscrews the screw at the other extremity and makes the cutters advance along the cylinder. Sixty turns of the axis cut one inch of the cylinder.



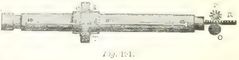


Fig. 191.

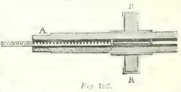


Fig. 192.

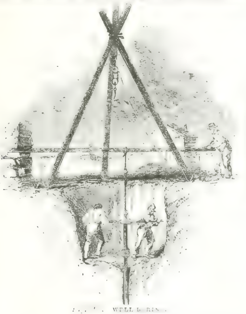
According to Billingsley's method, the cylinder is placed with its axis in a vertical instead of a horizontal position, in order that the boring dust and shavings may fall out instead of wearing and impeding the cutters. By this arrangement the cylinder is bored throughout without changing the cutters, and a more regular bore is thus obtained. Another advantage is, that the cylinder does not deviate from its cylindrical form by its own weight, which sometimes happens when large and slender cylinders are laid on their side. There is also often a loss of shape by improperly strapping and wedging down.

Before the general introduction of cast-iron water-pipes, there was a great demand for wooden pipes, which were formed by boring the trunks of trees. For this purpose the tree was well secured to a carriage, and a vertical spindle, driven by a trundle and face wheel, gave motion to a horizontal bar, carrying a borer or auger at its extremity. As this revolved, motion was given to another wheel, about whose shaft was a rope also attached to the carriage, so that as the borer cut, the tree was gradually drawn up to the work until the hole was cut through. A larger auger was then used, and the operation repeated until the bore was of the proper size. In some cases the tree was made to revolve against a fixed auger. In other cases the tree was fixed vertically, so that the chips could fall out as the work proceeded. An ingenious machine was also contrived for cutting out the core whole, so that it could be applied to other uses. In this case a hollow cylinder was formed, with a crown saw at the extremity, which, being made to revolve, cut its way into the tree, while the core entered the cylinder, and was thus preserved whole. A plan of this kind was patented by Mr. Murdock in 1810 for boring stone-pipes, the core forming round pillars of stone. An attempt was made to use the pipes as the common water-pipes of London; they were joined together by means of Parker's cement, but the vibration communicated to the roads by the carriages, loosened the joints and made the pipes leak.

A variety of boring tools, used in the arts, will be found noticed under AUGER.

One of the most important applications of boring, is in the formation of ARTESIAN WELLS.

The usual method of boring for this purpose, is to attach the borer, which differs according to the nature of the work, to iron rods, which screw together in lengths of from 10 to 20 feet. A circular motion is given to the borer by the workmen above, assisted, when required, by a vertical jumping motion, which causes the boring tool to work its way through the ground. It is usual to begin by digging a circular hole, about [illegible]



[illegible] WELL BORING.

In the centre of this hole the boring is carried on by two workmen assisted by a labourer above. The handle of the borer has a female screw in the bottom of its iron shank, into which the boring chisel is fixed, and a wooden bar or rail passing through its socket, with a ring at the top. If the ground be tolerably soft, the weight of the two men bearing upon the cross-bar, and occasionally turning it round, will soon cause the chisel to penetrate; but in rocky strata the chisel is struck down with repeated blows, so as to peck its way, the men frequently shifting their position, so that the chisel or auger may constantly have a fresh place to act upon, by which means the rock is broken and penetrated. This labour is greatly assisted by an elastic wooden pole, placed horizontally over the well, from which a chain is brought down and attached to the ring of the handle. This pole is made fast at one end, by being set in a heap of loose heavy stones; at the other end the workman gives it a slight up-and-down motion, corresponding to the beating motion of the men below, by which means, the elasticity of the pole, in rising, lifts the handle, and thus diminishes the labour of the men. When the hole has, in this way, been opened as far as the length of the chisel will allow, it is withdrawn, and a sort of cylindrical auger, furnished with an internal valve, shewn in section, Fig. 194, is let down for drawing up the dirt and loose stones; the auger being introduced and turned round, the rubbish will pass up through the aperture at the bottom, and fill the cylinder, which is then drawn up and discharged at the top, the valve preventing its escape at the bottom. An iron rod is next attached, and the operation of pecking is proceeded with. The auger is again introduced and the rubbish withdrawn. The necessity of frequently withdrawing the rods, and the continual additions to their length, increases their weight, and renders some mechanical assistance necessary. Three scaffolding poles are, therefore, erected over the pit, and tied together at the top, and from the centre is suspended a wheel and axle, or a pair of pulley blocks, for the purpose of hauling up the rods by means of a fork, Fig. 195, which is brought down under the shoulder, near the top of each rod, and made fast to it by passing a pin through two little holes in the claws. The rods are thus drawn up about 7 feet at a time, and at every haul a fork, Fig. 196, is laid horizontally over the hole, with the shoulders of the lower rod resting between its claws, by which means the rods are prevented from sinking, while the upper length is unscrewed and removed. In attaching and detaching these [illegible] Fig. 197, [illegible]

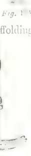


Fig. 1[illegible]

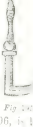


Fig [illegible]

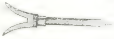


Fig 196.

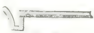


Fig. 1[illegible]7.

which they are turned round and the screws forced up to their firm bearing. The first 60 to 100 feet is bored to the diameter of about 2½ inches, and is cleaned out by a gouge of 2¼ inches in diameter: the whole is then widened by a chisel, 4 inches in diameter, furnished with a guide for keeping it perpendicular.

The vertical or jumping motion of the tool is often obtained by a windlass instead of the simple plan just noticed. The rods are suspended to the windlass by a rope coiled two or three times round it, and so adjusted, that if the man holds one end of the coil tight, there will be sufficient friction to raise the rods on putting the windlass in motion. On slackening the end of the rope held by the man, the coil becomes loose, and the rods descend with a force equivalent to their weight and the distance through which they have fallen. In this way a regular percussive action is gained by keeping the windlass continually in motion in one direction, while the workman alternately allows the rods to be drawn up a certain distance, and then by relaxing his hold allowing them to fall.

Instead of the arrangement of poles, Fig. 193, it is often desirable to erect a stage over the proposed boring. This stage consists of a stout plank floor, resting on strong puttocks, and well braced together by planks nailed transversely across. In the centre of this floor is a square hole, a little larger than the boring-rods, but not large enough to allow the hook, Fig. 195, to pass through. Wooden trunks or temporary iron pipes are fixed under the boring stage, as guides for the boring tools and permanent pipes, &c. The permanent pipes to be inserted into the bore are joined together and slung ready to be fixed when required. If the bore be through mottled clay, the sooner the pipes follow, the better, as the sand underneath is apt to blow up into the bore-hole, or the clay itself, if not stiff, may choke up the hole. These pipes are either of cast or wrought iron; the latter being generally used for small distances, and the former, being thicker, are used for very deep work, where much driving is required. The lower pipes of the series are usually perforated with small holes, when the spring is in sand; but when water rises from chalk or rock, no perforation is required, and the pipes themselves are only required to keep the hole open. In many cases in and about London, advantage is taken both of the main sand-spring and of the chalk-springs also: the perforated pipes are firmly driven into the former, and smaller pipes and a smaller bore are continued to the chalk. A length of wrought and cast-iron pipe is shewn in Fig. 198. The junctions of the pipes have nearly, and, in some cases, quite, an even face on the outside. The cast-iron pipes have generally turned joints and wrought-iron collars, usually flush inside as well as out. The collars are sometimes fixed on the pipes with screws; but when the joints are not turned, they are run together with metal, a plan which shuts out bad water on the outside. The wrought-iron pipes are seldom riveted, but have thin collars soldered on, not quite flush outside, and the melting of the solder previously run in the parts is effected by suspending an iron heater, Fig. 199, down the pipe. The pipes are slung down the well by means of a wooden plug, Fig. 200, with a pin or key passing through it; and this being inserted into the end of the pipe, which is cut reversely, as in Fig. 201, will clearly hold it, and by merely turning round the plug after slacking it, the pipes will be detached. By this plug also the pipes can be driven. This small groove can be used at any depth, and where it is completely out of sight of the workman.

Fig. 198.

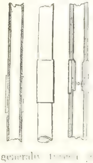


Fig. 199.

Fig. 200.

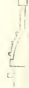
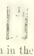


Fig. 201



Some of the tools used in boring are shown in the following figures :—

Fig. 202.

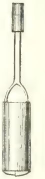


Fig. 203.

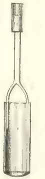
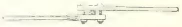


Fig. 204.



Figs. 202, 203, show an elevation and section of an auger. The tapped socket is to allow the rods to be screwed into it. A usual form of handle for turning round the rods is shown in Fig. 204. The leading nose is for cutting, and there is a valve within the cylinder for preventing the material cut from falling out when the auger is raised. Fig. 205 shows a small auger, with a longitudinal slit, and no valve: it is used for boring through clay and loam. In very stiff clay the slit may be wide; in soft clay, narrow; but in very moist ground this tool cannot be used. The lower figure is a plan, or horizontal section, of this tool. Fig. 206 represents an S chisel, for cutting through rocks, flints, &c. This tool is worked with a vertical motion, and in a circular direction. In boring through sand, or hard ground previously loosened by other tools, a large shell, shown in section, Fig. 207, is used: it contains two valves, opening upwards, one of which is shown in the figure. Fig. 208 is a spring rymer, in which the cutting edges are placed reversely, and the size is regulated by means of the screw and swivel. This tool is used for enlarging a hole. When the pipes are inserted some distance, it is important to widen the bore under them, to allow them to be driven further: this tool is therefore forced down the pipe in a partly collapsed state, springing to its set dimension as the softer ground under the pipe is cut away.

Fig. 205.

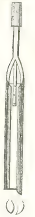


Fig. 206.

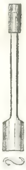


Fig. 207.

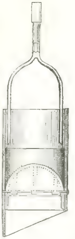
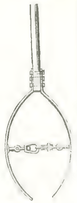


Fig. 208.



When very soft sand is met with, a tool fashioned like a common lifting pump is used; a vertical up-and-down motion filling the body of the tool with the soft matter. A useful boring tool for hard substances is a hollow cone, Fig. 215, with a spiral winding round it: as the boring goes on, the material accumulates in this cone, and may thus be raised to the working-stage.

In some cases, to ensure the vertical direction of the boring tools, guides are required: these are formed by bolting either to the tools or rods four wrought-iron bars, bent at the ends, so as exactly to fit the hole between the extremities.

Fig. 209.

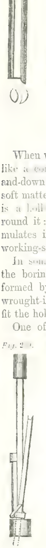
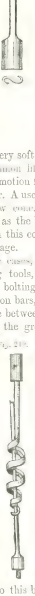


Fig. 210.



One of the greatest difficulties in boring arises from the occasional breaking of the rods. In order to extricate them tools have been contrived. Fig. 209 is a spring latch-tool, in which the forked hinge shuts by the action of a spring; so that when the tool is forced over the knob of the broken rod, as in the figure, the spring shuts the forked hinge under the knob, by which means the broken rod can be raised. When the knob cannot be easily got hold of, a screw, Fig. 210, is used. This tool is also applied when the weight to be raised will not overcome the friction of the screw.

Various other tools used in boring are described in works devoted to this branch of engineering, among which we may especially refer to M. Garnier's "Puits Artésiens," 4to. Paris, 1826. An excellent little "Treatise on Well-digging, Boring, and Pump-work," by Mr. Swindell, is published in Weale's Rudimentary Series. The following figures, copied from Garnier's treatise, will convey some idea of the great variety and complication of boring tools.

Fig. 211.

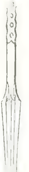


Fig. 212.

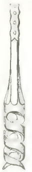


Fig. 213.

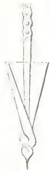


Fig. 214.

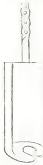


Fig. 215.

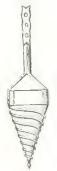


Fig. 216.

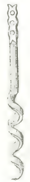


Fig. 217.

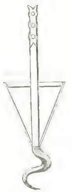
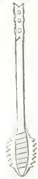


Fig. 218.

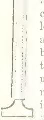


Such is a brief notice of the common method of boring Artesian wells. There is, however, considerable variation in the practice of different countries, and even of different districts, according to the geological nature of the place, and the views of the contractor. One of the simplest methods is that practised by the ingenious and industrious Chinese, who have from time immemorial been acquainted with the art of boring the earth for water or for salt brine. In the province of Szu-Tchhouan, on the borders of Thibet, occur a number of salt wells, accompanied by springs of inflammable gas; so that nature not only furnishes the brine, but also the fuel for evaporating the water and extracting the salt. There are several other wells of the same nature in the different districts of this department of Kia-Ting-Fou, and in the other neighbouring districts, situated to the east of the great chain of mountains covered with perpetual snow, which traverses the eastern part of Szu-Tchhouan, from south to north. According to the report of M. Imbert, there are in the vicinity of the town of Ou-Thouang-Khiao several thousands of these salt wells in a space of ten leagues by five. Every person who is tolerably rich takes a few associates with him, and digs one or more wells. The expense of digging a well is from seven to eight thousand francs (280*l.* to 320*l.*, a large sum in China), and the depth is commonly from 1,500 to 1,800

French feet, and five or six inches in diameter. They are usually bored in the solid rock. These people, who accomplish the most difficult undertakings with time and patience, begin by sinking vertically into the bed of earth, usually met with at the surface, a wooden pipe crowned with a hewn stone, perforated with a hole, which, like the pipe, has the same diameter as it is intended to give the well; that is, five or six inches. In this tube there is made to work a steel head of 300 or 400 lbs. weight. This steel is notched at the end, and is a little concave above and round beneath. A workman, by leaping upon the extremity of a lever, the other extremity of which is attached to the steel head, lifts it to the height of two feet, and lets it fall again by its own weight. Some pails of water are thrown in from time to time, to assist the trituration of the substances. The spur or steel head is suspended by a cord, to which is attached a triangular piece of wood, and each time that the lever raises the cord, a second workman, seated near the tube, makes the triangle perform half a revolution, so that the steel head may fall in a different direction. At noon the second workman ascends upon the lever to take the place of his companion. At night two other men take their place. When three inches have been bored, the steel head is withdrawn by means of a pulley, with all the substances with which its upper concavity is loaded. By this mode of boring, the wells are perfectly vertical, and their bore surface highly polished. Beds of sand, coal, &c., are frequently met with. The operation then becomes more difficult, and is sometimes entirely frustrated: for these substances no longer offering an equal resistance, the well loses its verticality; but these cases are of rare occurrence. At other times the iron ring which bears the steel head breaks. When this accident happens at a certain depth, the Chinese know no other means of remedying it than to employ a second steel head to break the first, an operation which may take several months. When the rock is good, an advance of nearly two feet is made in twenty-four hours, so that it may take about three years to dig a well. For a further notice of these wells see SALT.

A method of boring, known in some parts of Europe as the *Chinese system*, is founded on the above method, which consists in suspending the borer by a rope, which, when the tool is worked vertically up and down, imparts by its torsion a sufficient circular motion. In Fig. 219, the tool is shown surrounded by an iron cylinder. The pounded earth or stone collects in the circular space between the tool and the cylinder, by which means they can be brought up to the surface. Different tools are used for different strata, and the usual method of connecting the tool with a number of metal rods, as the work proceeds, is here dispensed with. The chief defect of this system is that the borehole is apt to become crooked, so that it is often impossible to sink the pipes required to protect the hole.

Fig. 219.



The great loss of time attending the plan of unscrewing and screwing, pulling up and letting down the rods, is a defect in the common method of boring. An attempt was made to remedy this by an apparatus patented by Beart, in 1844. The rod connecting the boring tool with the workmen above is formed of a tube with water-tight joints: into this tube water is allowed to flow, an upward and a downward current being formed by allowing the water to flow in one direction in the tube, and in the other in the circular space around it. It was supposed that in this way the rubbish loosened by the tool would be brought up to the surface. A portion of the finer material might certainly be got rid of in this way, but not the great bulk of loosened matter; and it is also an objection to the plan, that a large quantity of water is required in places where the very act of boring would seem to indicate a scarcity of that article.

In addition to the examples of remarkable Artesian wells noticed under that head, we may here give a few details respecting the most remarkable work of the kind that has yet been executed. In a letter to the *Times* newspaper, dated 17th August, 1850, Dr. Granville notices the completion of the great Artesian salt spring at Kissingen. He states that on the 12th August last, "the curious spectacle was exhibited of a column of water, 4 inches in diameter, springing with a prodigious force out of the earth to the height of 58 feet, from a depth of 1,878½ feet, spreading out like a graceful palm-tree at its highest point, and forming the finest and most striking jet-d'eau of this kind ever beheld. The water, as clear as crystal, issues from the soil with a temperature of 66° Fahr., charged with 3½ per cent. of pure salt, at the rate of 100 cubic feet per minute." Only one other such Artesian spring has been completed within the last two years, at Preussich Munden, in which the salt water is drawn from a greater depth, but rises to an elevation of 15 feet only, and is not so intensely salt.

The saline valley in which Kissingen is seated stands at an elevation of 650 feet above the level of the Baltic Sea. The stratification of its rocks, from the surface downwards, as it has been revealed by the successive borings, is extremely simple. The boring implements first went through 1,240 feet of variegated sandstone; then through 350 feet of sandstone of the Vosges formation; next through 150 feet of magnesian limestone (Zechstein); and lastly through 138½ feet of rock-salt, thus reaching a total depth, as before stated, of 1,878½ feet. In the latter, or rock-salt stratum (which is presumed to be 1,000 feet thick), a pure saline source (Soole) is formed, by a solution of the rock-salt in water. This solution has been found to hold not less than 27¼ per cent. of salt; and as there is little likelihood that they would be able to penetrate into the rock beyond 30 feet deeper, to that extent the perforation is to be pushed, and the well completed by the end of this year. At present the supply of water is at the rate of 100 cubic feet per minute, and the force with which this quantity is ejected to the height already stated is due to a source of almost entirely pure carbonic acid gas, which, having been met with at the depth of 1,680 feet from the surface, at the junction of the gypsum and zechstein, escaped with prodigious force into and out of the Artesian bore-hole, propelling the superincumbent column of water into the air, in the manner above mentioned. In the course of the boring operations, two distinct salt wells were gone through at 222 and 1,240 feet depths, with the respective temperatures of 59° and 66° Fahr., and 1¼ and 2½ per cent. of salt. It was under both these wells, at the depth of 1,680 feet, that the great carbonic acid gas stratum was first tapped. This stratum of gas would seem to be equally spread under and throughout the breadth of the valley, imparting its peculiarly piquant and pleasant character to the several mineral springs of this spa. The presence of so enormous a quantity of gas giving rise to an extraordinary commotion in the bore-hole, soon proved an impediment to the further extension of the latter. This induced Inspector Knorr to have recourse to a new and simple contrivance, by which he can arrest the flow of the gas into the Artesian bore, by compelling it to disperse itself through its subterranean recesses, whilst he proceeds downwards with his work of perforation. When the entire work shall have been completed, 3¾ cubic feet of brine per minute, free from iron and all other impurities, capable of yielding 50 lbs. of crystallized salt, will be conveyed to the boiling-house for crystallization, carrying with it a temperature of 92° Fahr. But it is intended to limit the whole annual produce of salt from this source to 6,000,000 lbs., which, at the current market price, will add to the revenue of the crown of Bavaria 300,000 florins, after deducting 60,000 florins for yearly expenses of work, fuel, and management. The whole cost of this work will amount to 80,000 florins (6,666*l.*). It was begun in the shaft of an old well, in 1832, from which time and during a period of 11 years, 800 feet only were bored through the rocks, the operation being often interrupted, and even suspended, from a feeling of discouragement; but, in 1843, Inspector Joseph Knorr, confidently predicting an ultimately successful result, advised the government to resume operations, which have never since been interrupted, either by day or night, and are now about to be completed.

BORON is met with in nature combined with oxygen, forming boracic acid. To separate the oxygen, a portion of boracic acid is heated with potassium in a tube; the oxygen partly combines with the potassium, forming potash, and that portion of the acid which is not decomposed, unites with the potash, forming borate of potash. The mixture is then placed in water, when the borate of potash dissolves, and the boron floats in the shape of a brown powder. Boron is of no importance in the useful arts; its chemical symbol is B.

Boracic acid is found in Thibet and in South America; but the principal supply in Europe is from the volcanic districts of Tuscany, called *Lagoons*, where jets of vapour, called *suffioni*, and of boiling water, charged with boracic acid, are continually issuing from cracks in the ground. Before the manufacture of boracic acid from these sources was undertaken, the district was a positive nuisance, both from the fœtid odour diffused around, and from the accidents which frequently occurred both to man and beast. "As you approach the lagoons," says Dr. Bowring, "the earth seems to pour out boiling water, as if from volcanoes of various sizes, in a variety of soils, but chiefly of chalk and sand. The heat in the immediate neighbourhood is intolerable, and you are drenched by the vapour, which impregnates the atmosphere with a strong and somewhat sulphureous smell. The whole scene is one of terrible violence and confusion:—the noisy outbreak of the boiling element; the rugged and agitated surface; the volumes of vapour; the impregnated atmosphere; the rush of waters among bleak and solitary mountains. The ground, which burns and shakes beneath your feet, is covered with beautiful crystallizations of sulphur and other minerals; its character beneath the surface at Monte Cerboli is that of a black marl, streaked with chalk, giving it at a short distance the appearance of variegated marble."

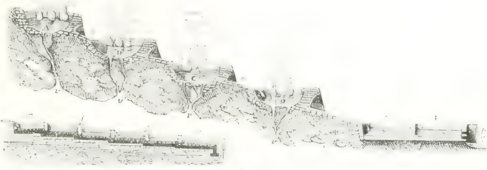


Fig. [illegible]

When the soil exhibits at any spot a high temperature, and vapours of sulphur ascend from it, or any earthquake is felt, a basin more or less deep, according to the locality, is dug there. A column of vapour suddenly issues with considerable force from the earth; this is surrounded with a wooden chimney, in order to protect the workmen. A suitable form is given to the basin, and the sides are lined with stone. The depth and circumference of such a basin must be in a certain relation to the force of the column of vapour; for, when the depth and surface are too great, and the basin contains too much water, the passage of the vapour is too much opposed, and it often seeks another exit. These eruptions of vapour, however, are not very constant, for the volcano, after being active for several years, may disappear, and seek a new passage, at a distance of from 30 to 60 yards. From the uncertainty of these eruptions, the localities are dangerous to visit without a safe guide; for when the eruption ceases at a certain spot, it is uncertain at what point it will break out: it then frequently forms a subterranean lake near the surface, which breaks through with the weight of a man, and a very dangerous scalding may be the result.

When the walls of the lagoon are finished, the chimney is removed, and water from some source is conducted into the basin, where it is heated to boiling by the ascending vapour, *v*, Fig. 220. The water, of which not much is evaporated, takes up from 1 to $1\frac{1}{2}$, and rarely 2, per cent. of boracic acid. The lagoons are emptied every day, as the amount of boracic acid is not increased by remaining longer, and the solution is conducted from one basin into another, as from A to B, by means of the pipe *o*, until it reaches the reservoir E E, where it deposits its mud, &c., which, not containing any more boracic acid, is removed from time to time, the clear liquor occupying the upper level *p*, and the mud *q*. The clear water is then conducted into the evaporating-pans G G, which are heated by the volcanic steam. In the course of 62 hours, during which the liquor is passed from one pan to another by means of the syphon-tubes *i i*, the solution is sufficiently concentrated, and is conveyed into wooden cooling-vessels, A, Fig. 221, where it is left three days to cool, and deposit crystals of boracic acid. The mother liquor is drawn off into channels B B, and returned to the clarifying reservoir, while the crystals of boracic acid, being first drained in baskets, C, are dried in chambers, D D, heated by volcanic vapour. The crystals are purified by dissolving them in two and a half times their weight of boiling water, and crystallizing a second, or even a third time, if the acid be required very pure.

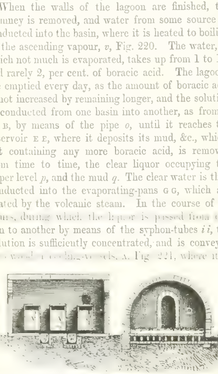


Fig. 221.

The dimensions of the lagoons vary from 100 feet in circumference, and 7 feet deep, to 500 and 1,000 feet in circumference, and 15 to 20 feet deep. The large ones enclose from 3 to 15 sources. The construction of these basins required considerable works; terraces had to be built, and hollows filled up, in order to keep the water at the proper level. Rivulets had to be turned out of their course, to prevent their influence on the basins.

In order to heat the evaporating-pans, &c., those sources are turned to account which are not suited to the construction of lagoons. The jets are surrounded in the manner before described, and thence conveyed in subterranean stone passages beneath the evaporating-pans. Each series consists of 14, 18, and 26 pans, 1 foot deep, and 10 feet superficies. The vapour condensed in the passages flows off through an aperture, and the uncondensed vapour escapes through a chimney.

In the year 1846 there were 400 evaporating-pans in operation, each of 10 feet surface, besides which there were several others with diaphragms, arranged in rows, 300 feet in length, in which the water, constantly evaporating, flowed slowly through the different divisions, until it was fit for the cooling vessels. Upwards of 1,200 lbs. of water are evaporated in the course of a day. Until the year 1827, wood was employed for heating the evaporating-pans; but since that time the economical method of heating by the volcanic steam has been adopted, by which a saving of about 10,000,000 francs has been effected. The production of boracic acid in 1846 amounted to 3,000,000 Tuscan pounds. It is stated, however, that the impurity of the acid increases every year, which is probably due to the progressive alteration of the strata, disintegrated by the currents of vapour, and the infiltrations of water. The first products contained from 90 to 92 per cent. of pure crystallized acid; but, according to M. Payen, they now contain from 18 to 25 per cent. of foreign matters.

The composition of boracic acid is

Oxygen	68.78
Boron	31.22
	100.00

Boracic acid is much used in the manufacture of borax, and also in the manufacture of paste for artificial gems; it has also been used with success in the manufacture of enamel.

Borax is a compound salt, formed by the combination of boracic acid with soda. It is first mentioned in the writings of the alchemist Geber, in the tenth century. It has a sweetish taste, and dissolves in 12 parts of cold, or 2 parts of boiling water. It unites with metallic oxides, forming various coloured glasses: with oxide of chrome, it forms an emerald green; with oxide of cobalt, an intense blue; with oxide of copper, a pale green; with oxide of tin, an opal; with oxide of iron, bottle-green, and yellow; with oxide of manganese, a violet; with oxide of nickel, pale emerald-green. The white metallic oxides produce a colourless glass. Borax is very useful as a flux, both to the goldsmith, in soldering the precious metals, and to the brazier, in soldering copper and iron, as it prevents the metal of the flux from oxidizing, and even dissolves any oxide that may have been formed. See APPENDIX.

BOTTLES. See GLASS, Sec. x.

BRANDY. A spirituous product obtained by distilling wine. Its qualities vary with the kind of wine employed. [See DISTILLATION.]

BRASS. An alloy of copper and zinc. The term is commonly applied to the yellow alloy of copper, with about half its weight of zinc, in which case it is called by engineers *yellow brass;* but copper alloyed with about one-ninth its weight of tin is the metal of brass ordnance or gun-metal. Similar alloys used for the *brasses* or bearings of machinery are called *hard* brass, and when employed for statues and medals they are called BRONZE. [See also ALLOY.] In this article will be noticed the alloys of copper and zinc only. In the language of the brass foundry a pound of copper is taken as the standard, and the founder in speaking of the proportions of yellow brass, says "6 to 8 oz. of zinc" ("to every pound of copper" being understood). In the following list of alloys of copper and zinc, the numbers at the beginning of each paragraph denote the ounces of zinc added to every pound of copper.

⅛ to ½ oz. This small addition is to enable the copper to cast soundly, which it does not usually do in its pure state. The addition is frequently made in the shape of 4 oz. of brass to every pound or two or three pounds of copper.

1 to 1½ oz. This forms gilding metal for common jewellery. It is made by mixing 4 parts of copper with 1 part of calamine brass; or 1 lb. copper with 6 oz. of brass.

3 oz. Red sheet brass made at Hegermühl, or 5⅓ copper and 1 zinc.

3 to 4 oz. Bath metal, Pinchbeck, Mannheim gold, similor and alloys with various other names. They resemble inferior jeweller's gold greatly alloyed with copper. Some of them contain a little tin.

6 oz. Brass that bears soldering. Bristol brass is said to be of this proportion.

8 oz. Ordinary brass, less adapted to soldering than 6 oz. as it is more fusible. This is also Emerson's brass, patented in 1781, and the common ingot brass made by simple fusion of the two metals.

9 oz. This proportion is one of the extremes of Muntz's patent sheathing. 10⅔ oz. is Muntz's metal, or 40 zinc and 60 copper. According to the patentee, any proportions between the extremes, 50 zinc and 50 copper, and 37 zinc 63 copper, will roll and work at the red heat, but the proportion 40 zinc to 60 copper is preferred. The metal is cast into ingots, heated to a red-heat, and rolled and worked at that heat into ship's bolts and other fastenings, sheathing, &c.

12 oz. Spelter solder for copper and iron is sometimes made in this proportion; for brass work, the metals are generally mixed in equal parts.

12 oz. Pale yellow metal, fit for dipping in acids.

16 oz. Soft spelter solder, fit for ordinary brass work, is made of equal parts copper and zinc. About 14 lbs. of each are melted together and poured into an ingot mould with cross ribs, which indent it into little squares of about 2 lbs. weight. Much of the zinc is lost in the fusing and casting, so that the ultimate proportion is less than 16 oz. The lumps are afterwards heated nearly to redness upon a charcoal fire, and are quickly broken up on an anvil, or with an iron pestle and mortar. If the heat be too great, the solder forms into a cake or coarse lumps, and becomes tarnished. At a proper heat it becomes nicely granulated, and remains of a bright yellow colour. It is then passed through a sieve.

16 oz., or equal parts, is one of the extremes of Muntz's patent sheathing.

16½ oz. Hamilton and Parker's patent Mosaic gold, which is dark-coloured when first cast, but on dipping assumes a beautiful golden tint. When cooled and broken, the yellowness disappears, and the tinge varies from reddish fawn or salmon-colour to a light purple or lilac, and from that to whiteness. The proportions are said to be from 52 to 58 zinc to 50 of copper, or 16¼ to 17 oz. to the pound.

32 oz., or 2 zinc to 1 copper. A bluish white brittle alloy, very brilliant, and so crystalline that it may be pounded cold in a pestle and mortar.

128 oz., or 2 oz. copper to every pound of zinc. A hard crystalline metal, differing but little from zinc, but more tenacious. It is sometimes used for laps or polishing discs.

The alloys from about 8 to 16 oz. to the pound are extensively used for dipping, as in the various brass articles used in furniture, &c. The metal is first annealed before it is scoured or cleaned, or the acids, lackers, or bronzes are used.

The ordinary range of good yellow brass, that files and turns well, is from about 4½ to 9 oz. With additional zinc, it becomes harder and more crystalline, and with less, more tenacious. Beyond 8 or 10 oz. the crystalline character of the alloys begins slowly to prevail. Up to this point, they maintain their malleability and ductility.

The red colour of copper merges into that of yellow brass at about 4 or 5 oz., and remains but little altered up to 8 or 10 oz. After this, it becomes whiter. [See ALLOY, App.]

The addition of zinc increases the fusibility of the alloy, but from the very volatile and inflammable nature of zinc in the furnace, the above named proportions must not be strictly taken, for whatever weight of the two constituents be put into the crucible, there will always be a rapid and to a certain extent uncontrollable waste of zinc.

Brass was manufactured by cementing sheets of copper with calamine or carbonate of zinc, long before the zinc was known in a metallic form, the zinc having been formed and united with the copper without becoming visible as a distinct metal. It is even now not uncommon to use the ore of zinc in making brass. For this purpose the native calamine, after being calcined for a short time, is ground in a mill, the galena contained in it is separated by washing, and it is then mixed at the same time with about a fourth part of charcoal. This mixture is put into large cylindrical crucibles with alternate layers of copper cut in small pieces, or in the form of shot.

Powdered charcoal is then thrown over the whole, and the crucibles are covered and luted up with a mixture of clay, sand, and horse-dung. The old form of furnace was a cone with the base downwards, and the apex cut off horizontally. The crucibles were placed upon a circular grate or perforated iron plate at the bottom, with a sufficient quantity of fuel thrown round them, and a perforated cover made of bricks or clay was fitted to the mouth, which served as a register to regulate the heat. The modern arrangements of a brass foundry are shown in section, in Fig. 222, with the moulding trough for the sand on one side, and the pouring or spill trough in the centre. [See Casting.] The furnace is usually built within a cast-iron cylinder about 20 or 24 inches diameter, and 30 or 40 inches high, which is covered over an ash-pit, reached through a loose grating on a level with the floor of the foundry. The mouth of the furnace stands about 8 or 10 inches above the floor, and its central aperture is closed with an iron plate, called a tile. The inside of the furnace is contracted to about 10 inches diameter by fire-bricks set in Stourbridge clay, except a small aperture at the back, about 4 or 5 inches square, leading into the chimney. There are generally three or four such furnaces standing in a row, and separate flues proceed from each into the great chimney or stack. Each furnace is furnished with a damper. The fuel is hard coke broken into lumps about the size of hens' eggs. The pot or crucible is usually put into the fire soon after it is lighted, with its mouth downwards, by which means the thin edge gets heated and expanded first, and the heat playing within the pot raises it gradually to a red-heat, and prevents the bottom from cracking. The pot is then bedded upon the fuel in its proper position, and an iron cover with a long handle put over it to keep out the small cokes while the man is making up the fire. The charge of metal is then put in, and three or four large pieces of coke are placed across the mouth of the pot; the *tile* is put on the furnace, and the damper adjusted to the proper heat, and the whole is left until the metal is run down. After the alloy is supposed to be formed, (the time varying in different works from 10 to 20 hours, according to the nature of the calamine, and the size of the crucibles,) the heat is increased so as to fuse the whole down into one mass. The tile is then thrown up, and a man standing over the opening grasps the crucible between the jaws of a pair of tongs, and lifts it out of the furnace. The refuse is skimmed off, and another man then seizes the crucible with a pair of tongs, and pours the contents into iron moulds placed in a sloping direction, guiding the stream with an iron rod as in Fig. 223. During this process there is a considerable combustion of zinc, the metal burning with its characteristic bluish white flame, and filling the whole place with dense fumes of white oxide of that metal, or *philosopher's wool*, as it was formerly called from its white colour and woolly texture. To prevent this from entering the lungs, the men tie a handkerchief over their mouths and nostrils during the casting. When the materials are good, a single fusion is sufficient to make good malleable brass; but the finer sorts undergo a second fusion with fresh calamine and charcoal.

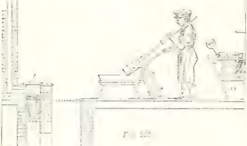


Fig. 222.

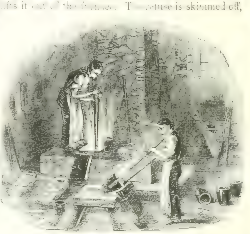


Fig. 223.—BRASS FOUNDRY.

If the brass is intended to be rolled into sheets, or made into wire, it is cast into plates between two blocks of Cornwall stone. The lower stone is fixed, and the face made smooth by filling up the recesses of the rough stone with fine sand. The upper stone, prepared in a similar manner, is suspended over the fixed one, the space or mould between the two being limited by iron bars laid on the lower stone, which is a little longer than the upper one, and projects to the front, so as to form a lip or mouth-piece for receiving the metal. The brass, whether in ingots or sheets, solidifies immediately, and can be turned out of the moulds directly the casting is complete.

The most certain method of forming the alloys of copper and zinc, is by the direct union of the two metals in given weights. The usual plan is to thrust broken lumps of zinc beneath the surface of the melted copper with tongs; but there is always a loss of zinc, and in every successive fusion, the more oxidizable metal wastes, so that the original proportion is more and more departed from. When the metals are not well covered with flux, the loose oxide frequently mixes with the metal, giving rise to white coloured stains in the brass, and little cavities filled with oxide of zinc.

Mr. Holtzapffel, in his work on "Mechanical

Manipulation," to which we are already indebted for some of our information contained in this article, has detailed a number of interesting experiments which he tried for ascertaining the best methods of forming alloys of copper and zinc. "The zinc was added to the melted copper in various ways; namely, in solid lumps, in thin sheet hammered into balls, poured in when melted in an iron ladle; and all these, both whilst the crucible was in the fire, and after its removal from the same. The surface of the copper was in some cases covered with glass or charcoal, and in others uncovered, but all to no purpose; as from $\frac{1}{4}$ to $\frac{1}{2}$ the zinc was consumed with most vexatious brilliancy, according to the modes of treatment; and these methods were therefore abandoned as hopeless. I was the more diverted from the above attempts, by the well known fact that the greatest loss always occurs in the first mixing of the two metals, and which the founder is in general anxious to avoid. Thus, when a very small quantity of zinc is required, as for so-called *copper castings*, about 4 oz. of brass are added to every 2 or 3 lbs. of copper. And in ordinary work, a pot of brass weighing 40 lbs. is made up of 10, 20, or 30 lbs. of old brass, and two-thirds of the remainder of copper. These are first melted. A short time before pouring, the one-third of the new metal or zinc is plunged in when the temperature of the mass is such that it just avoids sticking to the iron rod with which it is stirred."

Mr. Holtzapffel next determined to melt the metals on a much larger scale, and in the usual proportions, or 24 lbs. copper to 12 lbs. zinc. Then to ascertain the first loss of zinc. To re-melt a quantity of the alloy over and over again, taking a trial bar each time in order to ascertain the average loss of zinc in each fusion.

24 lbs. of copper, namely, clean ship's bolts, were first melted alone, and the loss was found to be barely $\frac{1}{4}$ oz. on the whole. A similar weight of the same copper was weighed out, and also 12 lbs. of the best Hamburg zinc, in cakes about $\frac{1}{4}$ inch thick, which were broken into about 8 pieces. The copper was first melted, and when the whole was nearly run down, the coke was removed to expose the top of the pot, and when all bubbling had ceased in the copper, the zinc was taken up with the tongs a lump at a time, held beside the pot for a few moments to expel the moisture, and then put into the copper with an action between a stir and a plunge. There was a flare and a low cracking noise as if butter had been thrown in. The zinc was absorbed, and the surface of the pot was clear from its fumes almost immediately. The remainder of the zinc was added a lump at a time, care being taken not to set the copper by inserting the lumps of cold metal too quickly. After each addition, the pot was free from flame in a few moments. A handful of broken glass was then thrown in, the tile replaced, and the whole allowed to stand for about 15 minutes, to raise the metal to the proper heat for pouring, which is denoted by the commencement of the blue fumes of the zinc. The pot was then taken from the fire, well stirred for one minute, and poured. The weight of the brass was 34 lbs. $12\frac{1}{2}$ oz., showing a loss of 1 lb. $3\frac{1}{2}$ oz., or $\frac{1}{10}$th of the zinc, or $\frac{1}{30}$th of the whole quantity. In another experiment, the loss differed from this by only half an ounce, and the mean of the two was $31\frac{1}{4}$ per cent. zinc, or instead of 8 oz. to the pound, it was only $7\frac{1}{4}$ oz.

12 lbs. of each of these brasses were re-melted six times, a bar of $1\frac{1}{2}$ lbs. being taken each time. The loss per cent. of zinc was exactly the same in each of the six experiments, that is, at the sixth melting each bar contained $22\frac{1}{2}$ per cent., or $1\frac{1}{2}$ oz. to the pound of copper. In each case the second fusion sustained the greatest loss, (nearly twofold,) and in the others the loss was pretty much alike.

In forming an alloy of 2.75 copper and 1 zinc, the proportions of which require to be very carefully preserved, as that alloy was found to expand equally with the speculum metal to which it had to be soldered, Lord Rosse found that by employing a furnace deeper than usual, and by covering the metal with a layer of charcoal powder 2 inches thick, the loss each time was the smallest, and almost exactly the 180th each casting. The charcoal dust was renewed by folding it up in paper and throwing it in.

BRAZIL-WOOD. A red dyeing material, obtained from one or two species of *Cæsalpina*, West Indian and South American trees, of the leguminous kind. The term, Brazil-wood-tree, was applied to these trees many years before the discovery of South America; and it is said that the portion of that continent now bearing the name of Brazil was so designated on account of the abundance of these trees found therein. Their importance was soon evident to the Portuguese government, and the name, *Pao de Rainha*, or Queen's Wood, was given to them, in token of the royal monopoly over their exportation. This wood has also the names of Pernambuco, wood of St. Martha, and of Sapan, according to the places which produce it. The tree is of large size, crooked, thorny, irregular of growth, with small leaves, and fragrant red flowers. The bark is exceedingly thick, and when removed, the heart of the tree, which is the only useful portion, is of comparatively small size. The wood is of a pale red when first cut, but the colour becomes deeper by exposure to the air. The thickest pieces, with a close grain, are the best. Boiling in water extracts the whole of the colour, and, if continued long enough, produces a very fine red. This colour is, however, very fleeting, and is used with alum, and tartar, and with various other mordants, which vary the shades of red considerably. The colouring matter of Brazil-wood is easily affected by the action of acids, producing an orange or yellow colour, which is durable. It is also sensitive to the action of alkalies, which produce various shades of violet and purple; but these are not to be depended upon, being, in general, very fleeting.

The colour known in the trade as false crimson (to distinguish it from cochineal-red), is given to silks by means of Brazil-wood; the silk being first boiled with twenty parts of soap per cent., then alumed, and refreshed at the river, and finally passed through a bath charged with more or less Brazil-wood, according to the colour required. Stronger colours are gained by first giving a ground of annotto to the silk, or by adding logwood to the brazil-bath, with a little alkali, if necessary. Nicaragua and peach-wood are also species of cæsalpina. Red ink is made by boiling two ounces of Brazil-wood for a quarter of an hour in a pint of water, and adding a little gum and alum.

The colouring principles belonging to Brazil-wood are known to chemists as brasiline and brasileine; the first being the colouring matter of the wood, and the second, a colourless substance, which appears to pass into the proper colouring matter by oxidization.

Within the last ten years, Brazil-wood has been in some measure superseded by a wood imported from Africa, which yields a finer and more permanent colour. It is called by the dyers *cam-wood*. The tree from which it is obtained grows at Sierra Leone, and in the interior of Africa, and is believed to be that known among botanists as *Bahia nitida*. In consequence of this, and of the vexatious monopoly on Brazil-wood, the importation of the latter has greatly declined, and is now inconsiderable. By the recent alteration in the tariff, it is admitted duty-free.

BRAZING. See SOLDERING.

BREAD. Many of the useful arts seem to have originated in the necessities of man's nature, which led him to use a great proportion of his food in a manner peculiar to himself, and thus raised him above the lower animals in not devouring it raw. When the difficulties of the subject are considered, it is not surprising that some nations regarded the useful arts as of divine origin; for in the absence of science, and of that spirit of inquiry which scientific researches so eminently encourage, what can be more difficult than the first step in the art of bread-making? It was, indeed, a great discovery in the early history of the world, that by moistening grain, and then subjecting it to the action of heat, a compact cake of food could be formed, containing within a small compass a large amount of nutrition, capable of being kept for a length of time, and yielding when masticated an agreeable relish to the palate. The second step was also a difficult one, namely, the reducing of the grain to powder before moistening it. This was done by pounding or *braying*[1] it between two stones, or in a mortar, a method still practised by some rude nations. But the third step must have been most difficult of all, namely, that of exciting fermentation, or combining with the bread a gaseous body identical with that which gives the foaming appearance to ale, and the sparkling appearance to champagne. The effect of this process is as remarkable as the process itself, for instead of a heavy, hard, tough, dull, indigestible mass, a light, porous, elastic food is produced, more agreeable to the palate, and more conducive to health. The two forms of bread here described are still in use, the one being the common sea-biscuit [*vide* BISCUIT], and the other the wheaten loaf. In well-made bread, the effect of the gas disseminated throughout its substance is remarkable. It forms the bread into vesicles, which are arranged in a succession of layers, one above another, perpendicular to the crust; a sort of structure called by the bakers *piled bread*, and regarded as a sure test of the success of the batch. The increased facility of digestion of well piled bread is thus shown by Dr. Colquhoun:[2]—If a portion of such bread, well baked and thoroughly cool, be pressed between the fingers, it will crumble readily into powder, and if placed in hot water, it will immediately swell, disintegrate, and admit of being easily diffused through the liquid. Whereas, unpiled bread pressed between the fingers remains a solid cohesive mass, and in hot water does not soften further than to become a permanently tough mass of dough.

The term loaf is said to be derived from the Anglo-Saxon *hlif-ian*, to raise or lift up, the dough being *loaf*, or raised by a fermenting substance named *leaven*, (Latin *levo*, French *lever*, to lift.) Hence the term *leavened* and *unleavened* bread. The word *dough* is said to come from the Anglo-Saxon *deawian*, to wet or moisten, so that *dough* or *dow* means wetted. Now, if a mass of dough be left to itself for a sufficient time, it will pass spontaneously into a state of fermentation or incipient decomposition, which will generate carbonic acid within it, and give the bread baked from it a lightened vesicular texture. A more speedy method than this is adopted in practice, but if a small portion of old dough in a state of active fermentation be diffused through a mass of fresh dough, the process of fermentation therein will be greatly accelerated. When this is done, the mass is said to be *leavened*, and the fermenting dough thus added is the *leaven*. In the earliest record of the history of man, we find that cakes and unleavened bread were made by Abraham. But leavened bread was well known in the time of Moses, for we find (Exodus xii. 15) a prohibition against the use of it during the passover. Hence it has been supposed that the use of fermented bread originated in Egypt. The Greeks refer the invention to the god Pan. The Romans derived it from the Greeks, and until about 200 B. C., when bakers were first established in Rome, the term "pulse-eating nation" was applied to the Romans by way of reproach. From Rome the art of making leavened bread was slowly introduced among the northern nations, and even at the present time, in the northern countries of Europe and Asia, fermented bread is seldom used except among the higher classes. In many parts of Sweden rye cakes, as hard as wood, are baked twice a-year, and form the common bread of the lower orders. And in Scotland, up to a recent period, barley bannocks and oaten cakes were the ordinary bread of the people.

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[1] According to Horne Tooke, the word *bread* is derived from *brayed* grain, from the verb to *bray* or pound in a mortar, the ancient method of making dough.

[2] Chemical Essay on the Art of Baking Bread, Annals of Philosophy, Vol. XII. New Series, 1826.

The only substance adapted to the making of good fermented bread is the flour of wheat, a grassy plant, the *triticum* of botanists. It is more extensively cultivated than any other plant, and like man, seems to adapt itself to nearly every climate. Excellent crops of it have been raised in the latitude of 60° N., and it is cultivated in the East Indies within the limits of the torrid zone. Its original habitat is unknown. It improves in quality as it advances south, within certain limits. Thus, the wheat of Essex and Kent is of better quality than that of East Lothian and Berwickshire. The French wheat is better than the English, the Italian better still, but the wheat of Barbary and Egypt is probably the best in the world.

The essential constituents of wheat flour are *starch*, also called *farina* or *fecula*, *gluten*, and a little *sugar* and *albumen*. According to Vogel's analysis, 100 parts of wheat flour contain starch 68 parts, gluten 24, gummy sugar 5, and albumen 1.5; but these proportions vary with the goodness of the wheat.[1]

The STARCH of wheat flour is very nutritive. It is a white, crisp, crystalline substance, insoluble in cold water, but forming a thick paste with hot water. When roasted till it becomes brown, it is rendered soluble, and acquires the properties of gum. When boiled for a long time in very dilute sulphuric acid, it is converted into a species of sugar. See STARCH.

GLUTEN or GLUTINE can be separated from wheat flour by tying up a portion of flour in a coarse cloth, and kneading it under a stream of water till the starch and soluble matters are washed out, and the water runs off clear. The gluten left in the cloth is a grey, viscid, tenacious, insoluble mass. When moistened, it undergoes a species of fermentation. Bubbles of gas separate from it, and in about ten or fourteen days it acquires the smell and taste of cheese. Gluten is a mixture of vegetable fibrine and a small quantity of a peculiar matter containing nitrogen called *gliadine*, to which its adhesive properties are due. Gliadine is gluey and adhesive, insoluble in water, and when dry, hard and translucent like horn. The fibrine of other grain does not contain gliadine. Barley and oatmeal yield no gluten, but these and other vegetable substances, such as potatoes, and even turnips, can be made into fermented bread by the addition of gluten or of wheat flour. 2 parts of wheat flour and 1 part of boiled potatoes form an agreeable bread. The starch of potatoes is a very beautiful substance; mixed with a little gum tragacanth, it is often sold as Indian arrow-root.

The small proportion of SUGAR in wheat flour, enables it to ferment on being mixed with water, without the addition of yeast. Thus the dough of wheat flour by spontaneous fermentation becomes converted into leaven. In the first part of the process, the fermentation is entirely confined to the sugar; and here the process ought, if possible, to be arrested; but as this is not always possible, the vinous fermentation passes into the acetous, and a portion of vinegar is formed. It was formerly supposed that the fermentation of the dough made from wheat flour was peculiar to itself, and it was hence called *panary fermentation*. This is now known to be a mistake; for if the sugar be previously washed out of the flour, there will be no fermentation. During the rising of the dough, carbonic acid is formed at every part, and is prevented from escaping by the gluten, which forms a kind of adhesive web. The formation of the gas causes the dough to swell in every direction, and the particles of starch to separate, in which condition the process is arrested by the heat of the oven, so that when the bread is cut open, it is piled or full of cavities, each of which in the dough contained a globule of carbonic acid.

If the milky water obtained by washing wheat flour in order to separate its gluten, be allowed to repose for a few hours, it becomes clear by depositing a quantity of starch. If this liquid be boiled, it becomes turbid from the production of a flocculent precipitate, which, when collected, washed, dried, and purified by boiling with ether, is found to have the same composition with animal albumen. See ALBUMEN.

In the preparation of wheat for the manufacture of bread, the ground grain is usually separated into three parts, the *flour*, the *pollard*, and the *bran*. The bran is the outer husk of the grain, and is not used as food except for horses. The pollard is the part next the husk, and is coarser and darker than the flour, which forms the interior or central portion of the grain. The flour forms on an average about three-fourths of the wheat ground. In the preparation of wheat, the miller forms different kinds of flour, some of which are very fine and white, others coarse and unpalatable. The white flour is pleasing both to the eye and to the taste, and in London there is so strong a prejudice in favour of white bread, that scarcely any bread which is not white will find a sale. Hence the baker resorts to various methods of bleaching, which will be noticed hereafter. There are, however, seven distinct kinds of flour or meal produced in England from a quarter of wheat, namely:—

Fine flour	5 bushels	3 pecks.
Second flour . . .	0 ,,	2 ,,
Fine middlings . .	0 ,,	1 ,,
Coarse middlings .	0 ,,	0.5 ,,
Bran	3 ,,	0 ,,
Twenty-penny . .	3 ,,	0 ,,
Pollard	2 ,,	0 ,,
	11	2.5

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[1] Mr Edlin, in his "Art of Bread Making," London, 1805, found in one pound of good wheat,

Bran	3 oz.	or [illegible]
Starch	10	or [illegible] nearly.
Gluten	0 .. 6 drachms	or [illegible]
Sugar	0 .. 2	or [illegible]
Loss in grinding and reducing the flour to starch	2	
	1 0	

The albumen appears to have escaped his notice.

Thus wheat by being ground into flour almost doubles in bulk. During the bolting, a fine white gritty substance, called [illegible], is obtained. This is the finest portion of the grain, and is sold to the biscuit bakers; or being ground again, it forms the finest flour.

Now it is important to inquire whether the practice of consuming none but the whitest bread, even supposing it to be pure, is conducive to health and economy. In the preparation of wheat, the miller cannot entirely separate the bran, and hence a portion of it is ground up with the flour; but by sifting he separates it more or less completely, and thus obtains his seconds, middlings, &c. The *whole meal*, as it is called, of which brown household bread is made, consists of the entire grain ground up together, and used as it comes from the millstones; it therefore contains all the bran. By rejecting the bran, as we do when the finest flour only is used for bread, we actually lose a large amount of nourishment of the most important kind.

If we examine the composition of the two portions of the grain, the fine flour and the bran, we shall be able to ascertain how much they respectively contain of the several constituents of the animal body. Professor Johnston has put the subject into a practical form, by showing the value of whole meal or household bread, in forming and sustaining the three principal solids of the human body—fat, muscle, and bone.

1. *The fat.* Of this ingredient 1,000 lbs. of

Whole grain contribute	38 lbs.
Fine flour	20 ,,
Bran	60 ,,

So that the bran is much richer in furnishing the materials of fat than the interior part of the grain, and the whole grain ground together is richer than the finer part of the flour, in the proportion of nearly one-half.

2. *The muscular matter.* 1,000 lbs. of whole grain, and of the fine flour, contain of muscular matter respectively—

Whole grain	156 lbs.
Fine flour	130 ,,

So that of the material out of which the animal muscle is to be formed, the whole meal or grain of wheat contains one-fifth more than the finest flour. For maintaining muscular strength, therefore, it must be more valuable in an equal proportion.

3. *Bone material and saline matter.* 1,000 lbs. of bran, whole meal, and fine flour, contain respectively—

Bran	700 lbs.
Whole meal	170 ,,
Fine flour	60 ,,

So that in regard to this important part of our food, necessary to all living animals, but especially to the young during their growth, the whole meal is three times more nourishing than the fine flour.

Taking the three essential elements of a nutritive food thus existing in wheat, and comparing their respective amounts in the whole meal and in the fine flour, we find that on the whole, the former is one-half more valuable for fulfilling all the purposes of nutrition than the fine flour. "It will not be denied," says Professor Johnston, "that it is for a wise purpose that the Deity has so intimately associated in the grain the several substances which are necessary for the complete nutrition of animal bodies. The above considerations show how unwise we are in attempting to undo this natural collocation of materials. To please the eye and the palate, we sift out a less generally nutritive food—and to make up for what we have removed, experience teaches us to have recourse to animal food of various descriptions. It is interesting to remark, even in apparently trivial things, how all nature is full of compensating processes. We give our servants household bread, while we live on the finest of the wheat ourselves. The mistress eats that which pleases the eye more, the maid, what sustains and nourishes the body better."

It has been found by Majendie and others, that animals died in a few weeks when fed only upon fine flour, but lived long upon whole bread. Thus, the coarse bread given to prisoners is the best they could have, for being restricted from all other food, there would not be sufficient nutriment in fine white loaves to sustain life for a length of time. The nutritive properties of bran are exhibited in its effects in fattening pigs, &c., and thus, this apparently woody and useless material is found to produce valuable results.

Wheat, taken in the natural mixture found in the whole seed, is the most nutritive of all vegetable substances, and is therefore, when at a moderate price, quite as economical as some of the cheaper kinds of grain. It is only when wheat is very scarce, and consequently very high priced, that substitutes are sought for it in inferior articles. According to Liebig, Boussingault and others, 107 parts of wheat are equal in nutritive power to 111 of rye, 117 of oats, 130 of barley, 138 of Indian corn, 177 of rice, 894 of potatoes, and 1,335 of turnips.

The process of machinery by which wheat grain is converted into flour next demands attention. The ordinary flour-mill is an object with which we are all familiar, and is generally associated with much that is picturesque and beautiful. If the power employed be water, the mill is usually situated in a valley enriched by some considerable stream, and luxuriant in vegetation—the favourite resort perhaps of the angler, and the chosen sketching ground of the landscape-painter, to whom "an over-shot mill" seems an especial object of delight. Whether the power employed be steam, wind, or water, the machinery of a flour-mill is much the same: but as we have recently explored a water-mill, seated in one of the picturesque spots above referred to, the description of the machinery will be taken from thence, with such trifling variations as our observation of other flour-mills may suggest.

The moving power in mills of this description is a broad and heavy wheel, occupying the whole of the space between the walls of a chamber in the basement through which the stream rushes. This wheel may be what is termed *undershot*, *overshot*, or *balance*, but our present description applies to an undershot wheel. The circumference is provided with a number of projecting boards called *float-boards*, which being exposed to the action of a running stream, (generally increased by an artificial fall,) cause the wheel to be driven round, and thus to communicate motion to all the rest of the machinery. The overshot and balance wheels are close boarded, or close-soled as it is called, round their circumference; that is, they are closed in the spaces between the float-boards, but the undershot wheel is open.

When the wheat is brought in sacks to the mill, it is hoisted from the wagon to an upper floor, whence, in due time, and being properly cleaned, it descends to the mill-stones by means of a hopper, the quantity being regulated so that an equable flow of grain shall be continually supplied. The mill-stones are two large circular stones placed one above the other, but not quite close enough to touch. The lower is immovable, but through its centre the spindle rises on which the upper stone revolves. Motion is given to this spindle, and consequently to the upper stone, by cog-wheels below, connected with the great water-wheel or first mover. Through the hole in the centre of the upper stone the corn is admitted by means of a funnel. The surfaces of the stones are plane or flat, but they have a number of shallow furrows cut in them for the passage of the flour, which is forced out on all sides after it has been fully pulverized by the action of the stones. But it does not escape to any great distance, for a large wooden case covers in the stones while they are in

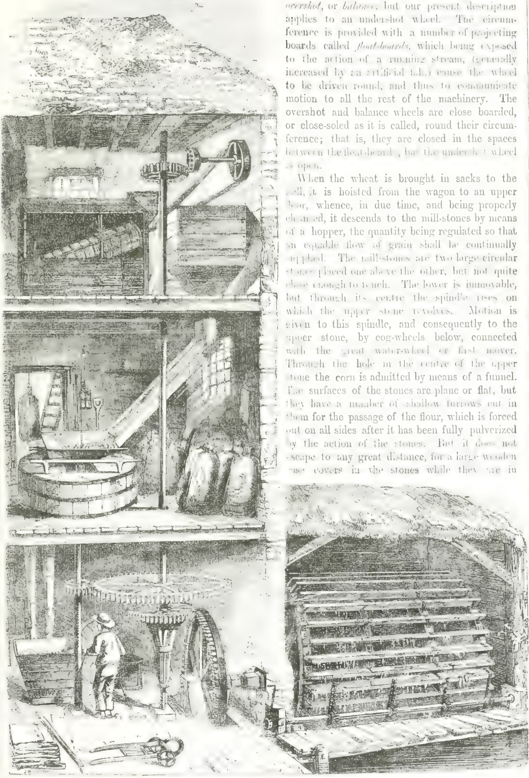

Fig. [illegible] DETAILS OF A FLOUR MILL.

action, and confines the flour to a certain space of the floor of the room. Within this space there is a small opening in the floor, through which, as the case becomes full, the flour rapidly falls, and is conveyed by a spout to its destined bin. The channels or furrows in the mill-stones are arranged in a particular order, there being frequently eight long ones from the centre to the circumference called master-furrows, and twenty-four shorter ones, arranged in the manner here represented. Each furrow is cut perpendicularly on one side and obliquely on the other, which gives it a sharp edge. Both stones are cut exactly alike; hence it follows, that when the upper one is turned over, and its position reversed, the sharp edges then come opposite each other and when in motion, they meet, and cut the corn to pieces. The plane parts of both stones are called "lands."

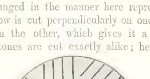
Fig. 225.

The bedding of mill-stones is a matter of great importance, and the requisite firmness is usually secured by a cast-iron frame-work, fitted with screws, and supported by the cross timbers of the flooring of the mill. A patent was taken out in 1821 for fixing the stone in a cast-iron frame, embedded in plaster-of-Paris, and of one uniform strength, but the plan has not been generally adopted. Mill-stones are of various materials, but those in general use for grinding wheat are made of a very hard siliceous stone imported from France, the technical name being *burr* or *buhr*. This stone is so porous that it sometimes requires to be filled up in parts, with a composition of alum and grit; and yet it is so hard, that a pair of stones in full work will last twenty or thirty years. The mill-stone is not one solid piece, but is made up of a number of pieces, cemented by plaster-of-Paris, and secured by iron hoops round the circumference. Burr-stones are a rare geological formation, and are found in abundance only in the mineral basin of Paris, and some neighbouring districts. The finest quarry of them is near La Ferte sous Jouarre.

There is much difference of opinion as to the best size of mill-stones, and the velocity which should be employed. The generality of mill-stones are from 4 to 5 feet in diameter, and make from 80 to 100 revolutions in a minute; but the tendency at present is to diminish their size, and increase the velocity of their revolutions. Great velocity generates heat, which with the large stones is very injurious to flour, and produces a condition of that article known to millers as *greased*, indicated by a soft and slippery feeling; but it is found that with small stones, although the velocity be great, the corn does not remain long enough under them to arrive at this condition. The only disadvantage of the small stones seems to be, that, in dressing the flour prepared from them, more middlings or sharps are made than by the large ones. Where meal of a very superior quality is required, a *sheeling-machine* is added to the rest of the apparatus, and the wheat is first passed through a cylindrical sieve, to remove all impurities, and then between a pair of mill-stones, called sheeling-stones, which remove nearly all the bran without breaking the corn. These stones are not cut into channels, nor are they brought so near together as the grinding-stones. The sheeled wheat is received into a sieve, and afterwards into a fanning-machine; and when, by the action of these, the bran is entirely separated, it is then ground into flour, which is of remarkable whiteness and purity, although for the purposes of nutrition it is not improved by this process. Without reference to this refined method, the ordinary fine flour is produced by wheat of the best quality, well and perfectly ground; that is, having the bran and the flour completely separated, without reducing the bran to such small particles as to allow of its going through the dressing-machine with the flour. The miller's own experience can alone guide him in grinding well, and keeping his millstones in proper order. The evils of over-grinding and under-grinding have both to be guarded against: the former injuring the flour; the latter subjecting the miller to loss. Damp wheat clogs and impedes the stones, and leaves no remedy but fresh dressing them; therefore, if dryness cannot be attained by natural means, kiln-drying must be adopted, although the wheat is deteriorated thereby.

Wheaten flour, in common with every other article of commerce, is subject to adulteration; but, fortunately for the consumers, the adulterating material is not unwholesome. This is generally bean or pea-flour, and is not used in sufficient quantity to make it of serious importance; while in some of the more extensive mills, we are assured, adulteration is unknown.

Flour is *dressed*, or separated from the bran, by means of a *dressing-machine*. This is an ingenious contrivance, in the form of a long hollow cylinder, placed in a slanting position, and covered internally with wire-cloth, of varying degrees of fineness. Externally, the framework of the cylinder is composed of longitudinal and circular ribs of wood, placed at regular distances from each other. Inside the cylinder is a revolving reel, with hair brushes attached, Fig. 226. These extend the whole length of the cylinder, and, as they revolve, brush against the wire-cloth lining of the cylinder, agitating and driving through its interstices the finer portions of the meal, which had been previously taken from the mill-stones in sacks, and raised by means of sack-tackle to an upper floor, whence it now gradually descends through a spout into the dressing-machine. The finest of the flour will go through the upper end of the cylinder,

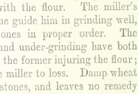
Fig. 226.

because the finest wire-cloth is placed there; the next finest through the next division; then the middlings, through the next division; and, finally, the pollards, or sharps, through the last division; while the bran, being too coarse to go through any of the divisions, is discharged at the lower end of the cylinder. The whole of this apparatus is enclosed in a large box, to prevent the waste of flour which would otherwise take place. The lower part of the box is divided into compartments, into which the flour falls, according to its several degrees of fineness, and can thus be kept distinct; but these divisions can be shifted at pleasure, so as to vary the qualities of the flour. When the meshes of the cylinder become clogged, as in the course of time they always do, a brush, acted upon by the machinery, is applied to the exterior, and clears it in a much shorter time than it could be done in the old way by hand. The pinion for turning the dressing-machine should be made to revolve in either direction, because the hair of the brushes becomes bent, and worn on one side, requiring to have the action reversed.

The dressing-machine is a great improvement on an earlier method, called the bolting-mill, which is not, however, out of use. Both machines are employed in the flour-mill lately visited by the writer. The bolting-mill, Fig. 227, is a long reel, covered with a peculiar kind of cloth, somewhat similar to that of which shrouds are made. This reel, with its cylindrical cover of cloth, revolves rapidly, and in so doing comes in contact with a number of bars of wood, called *beaters*, striking against them with considerable force, and thus forcing the finer portions of the meal within the cloth to escape through its substance. The bolting-cloth is, in fact, a cylindrical sieve, and its chief defect is that, in sifting the meal, it produces only one quality of flour, instead of several, as in the dressing-machine. On this account it is necessary to have bolting-cloths of different degrees of fineness, and to change them according to the sort of flour required. The bolting-cloth is terminated at each end by a broad piece of white leather, neatly sewed on, with a drawing-string round it. The leather answers the double purpose of strengthening the bolting-cloth, and allowing the miller to fasten it securely to the reel. The bolting-mill, like the dressing-machine, is placed in an inclined position, and the refuse falls down to the tail end. This apparatus is also enclosed within a box, to prevent waste of flour.

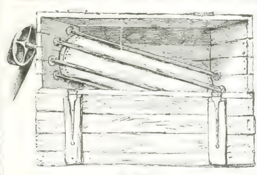

Fig. 227.

From the several varieties of flour obtained by the above processes, three kinds or sorts of bread are usually manufactured in Great Britain. 1. Wheaten bread, or *firsts*, which is made of the finest flour; 2. Household bread, or *seconds*, which is somewhat coarser; 3. Brown bread, or *thirds*, which is made of flour of various degrees of coarseness. With wheat of the same quality, the coarseness or fineness of the flour depends, as already noticed, on the dressing, or separating of the husks of the wheat, after being ground. For making firsts, the flour is entirely separated from the bran or husks; in the other descriptions, the bran is not entirely removed, but the coarse broad bran is separated from the coarsest flour.

The bake-house ought to be a large room, with a dresser on one side, with suitable shelves above it. On another side is the kneading-trough, which is about 7 feet long, 3 feet high, 2½ feet broad at the top, and 19 inches at the bottom, with a sluice-board, to pen up the dough at one end, and a lid to shut down. The third side contains a copper, capable of holding 3 or 4 buckets of water. The oven occupies the fourth side: this may be 3 or 4 feet high, with an arched roof, and a brick or stone floor, furnished with a door to shut close. The fire-place is usually at one side, and the heat is communicated by winding the flue round the oven. A portion of the fire is also used for heating the copper. The proper temperature of the oven for baking is about 450°; the bakers, however, do not use a thermometer, but judge of the heat by throwing flour on the floor; if it soon blackens, without taking fire, the heat is judged sufficient..

The utensils of the bake-house consist of, 1. The *kneading-trough*; 2. The [illegible], made of hair, or of tinned iron, with holes drilled through it; 3. *Wi[illegible]*, for sifting the flour; 4. A *bushel*; 5. A [illegible]; 6. A [illegible] or [illegible]; 7. A *water-tub*, placed near the oven; 8. A *yeast-tub*; 9. A *dough-knife*, about the size of a large carver, with a round blunt point; 10. *Scales* and *weights*; 11. A *scraper*, made like a hoe fixed on a short wooden handle, and used for scraping the dough out of the trough and moulding-board; 12. Four or five *peels*, of different sizes; the peel being a sort of shovel, with a long handle, used to set the bread in the oven, and also to take it out; 13. *Tins*, or *iron plates*, for baking buns, pies, puddings, &c. on; 14. Coarse thick *flannels*, for covering up the dough and the bread; 15. A *rasp*, or broad flat file, with a wooden handle, for rasping burnt crust off bread; 16. The *scuttle* or *swabber*, a quantity of wet netting at the end of a pole, about 8 feet long, for cleaning the oven, preparatory to setting the batch; 17. *Set-ups*, or four-sided oblong pieces of beech, for placing on both sides, and at the back and front of the oven, to keep the loaves in their places; 18. The *rooker*, a tool resembling the letter L, fixed in a wooden handle, for the purpose of drawing out the ashes from the oven; 19. A *hoe*, which is used for a similar purpose.

At the time when Dr. Colquhoun's essay was written, the following appears to have been the practice of the London bakers in the manufacture of bread by means of yeast-fermentation. The baker generally takes a portion only of the water which he intends to employ in making the required quantity of dough. The temperature of the water varies from 70° to 100°, and contains a portion of the salt necessary to give the bread its proper flavour.(1) Yeast is next mixed with the water, and then a portion of flour is added, always less than the quantity intended for the finished dough. The mixture is covered up and left in a warm situation. The substance thus set apart is called the *sponge:* its formation and covering-up is termed *setting the sponge*, and according to the amount of water in the sponge, with reference to the whole quantity used in the dough, it is called *quarter*, *half*, or *whole sponge*. In about an hour, the mixture thus set apart begins to ferment. It swells out, and heaves up, evidently in consequence of the generation of some internal elastic fluid, which in this instance is always carbonic acid gas. If the sponge be of a semi-fluid consistence, large bubbles of gas soon force their way to the surface, where they break and dissipate in rapid succession. But when the sponge has the consistency of a thin dough, it confines the gas within it until it dilates equably and progressively to nearly double its original volume, when, no longer capable of containing the pent-up air, it bursts and subsides. This process of rising and falling might be carried on actively and frequently during many hours, but experience has taught the baker to guard against allowing full scope to the energy of the fermentation. He generally interferes after the second or third dropping of the sponge, and were he not to do so, the bread formed from this dough would be sour to the taste and smell. At this period, therefore, he adds to the sponge the remaining proportions of flour and water, and salt, which may be necessary to form the dough into the required consistence and size; and next incorporates all these materials with the sponge by a long and laborious course of kneading, Fig. 228. When this process has been continued until the fermenting and the newly added flour have been intimately blended together, and until the glutinous particles of the flour are wrought into a tough and elastic dough, so that it will receive a smart pressure of the hand without adhering to it, the kneading is for a time suspended. The dough is left to itself for a few hours, during which time it continues in a state of active fermentation throughout its whole extent. It is next subjected to a second but much less laborious kneading, the object of which is to distribute the gas within it as equably as possible throughout the whole mass, so that no part of the dough may form a *sad* or ill-raised bread from the deficiency of gas, or be too spongy from its excess. After the second kneading, the dough is weighed out into the portions requisite to form the kinds of bread desired. These portions of dough are shaped into loaves, and once more set aside for an hour or two in a warm place. The continued fermentation soon generates a sufficient quantity of carbonic acid to expand each mass to about double its former volume. They are now considered fit for the fire, and are finally baked into loaves, which when they quit the oven are nearly twice as bulky as when they had entered it. The generation of the due quantity of gas within the dough is necessary before placing it in the oven, because as soon as the dough is exposed to a great heat, the process of fermentation is arrested, and it is only the previously contained gas, which expands by the heat throughout every part of each loaf, that swells out its whole volume, and gives it the piled vesicular structure. Thus a well-made, and well-baked loaf, is composed of an infinite number of cellules, each of which is filled with carbonic acid gas, and lined with or composed of a glutinous membrane; and it is this that communicates the light, elastic, porous texture to the bread.

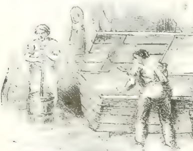

Fig. 228.—THE KNEADING-TROUGH.

The next process is that which is actually practised at the present day. It is given in Mr. Charles Knight's excellent series of works, published under the general title of "Guide to Trade." The number entitled "The Baker" has furnished us with several useful hints in the preparation of this article.

Take a peck of potatoes, (about 8 lbs.) and boil them with their skins on; mash them in the seasoning tub, add 2 or 3 quarts of water, about the same quantity of patent yeast,(1) and 3 or 4 lbs. of flour. Stir them well together, and cover the mixture up close with a sack, and let it stand for 6 or 12 hours, when it will have become what is called *ferment*. Then empty or sift a sack of second flour into the trough, and take a little less than one quarter of the sack of flour, and pin or block it up to one end of the trough with the pin board. Then bring the seasoning tub with the ferment in it to the trough, pour in a sufficient quantity of warm water, (in summer, cold,) stir up the mixture with the hands, and mash any lumps of potatoes that may be in it. Next, strain it through a sieve, to separate the skins of the potatoes; then pour the mixture liquor into the flour which had been previously pinned or blocked up at one end of the trough, and mix it well into the flour with the hands. Sprinkle a little flour over the top, and let it stand 5 or 6 hours, during which time the sponge will have risen twice. The first rising is suffered to break and go down. In about an hour or so, according to the heat of the bakehouse, the sponge rises a second time, and just as it is about to break again, or when the air escapes by the bursting of the bubbles, about 3 pailfuls of water to make up the batch are poured into the sponge from the seasoning tub, the water having dissolved in it about 4 lbs. of salt and 8 oz. of stuff, (some use 16 oz. of stuff, or even more.) The liquor ought to be well mixed with the sponge; which being done, the pin-board is taken away, and the whole of the flour is worked up into one mass, which is blocked up by the pin-board to one end, and left about an hour in summer, and 2 hours in winter to *prove*. The vacant part of the trough is then sprinkled with flour, to prevent the dough from sticking, the pin-board is knocked out, and the dough is pitched out of the trough on the lid of the opposite trough, when it is cut into masses and weighed, or *scaled off* as it is

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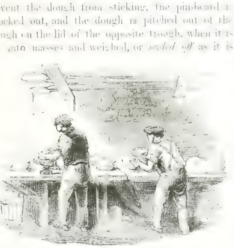
(1) The [illegible] has [illegible] process of fermentation. See [illegible]

(1) This is prepared as follows:—Half a pound of hops is boiled in two pailfuls of water till the liquid is reduced to one pailful; the decoction is then strained, and when sufficiently cool, half a peck of malt is added. The hops strained off are again boiled in the same quantity of water until it is reduced one-half, the hot liquid is strained into the former. The hops are boiled the third time, and the liquor strained into the former. When the whole has cooled down to blood heat, two quarts of patent yeast are added. Brewer's yeast will not answer. A little flour is added to the malt and hops, but this may be dispensed with in summer. In this way 5 gallons of good yeast are prepared. It is ready for use the next day. It occupies 7 or 8 hours in the making, but gives very little trouble to the baker.



called. These masses are then moulded into shape, and put aside in a regular manner to be finally moulded into loaves, taking care to mould those first which were first scaled off. Previous to moulding, the oven must be well swabbed out, and the up-sets chalked, to prevent the bread sticking to them. They are then placed at the back and on each side of the oven by means of the peel. The long loaves, or the quartern and half-quartern bricks, are put into the oven, packed together as close as possible. The common round bread is also packed close, but the cottage bread must be placed separately, each loaf by itself, or it will not be crusted all round.

After *setting the batch*, that is, placing the loaves in the oven, (Fig. 280,) which requires a good deal of skill, a set up is placed in front of it. The potatoes for the next ferment are put into a kettle, and placed

in the oven to boil. When the potatoes are done, and while still hot, the ferment for the next batch must be mixed. Twenty-four hours elapse from the mixing of the ferment to the time when the bread is taken out of the oven.

In this process we see that the London baker in the manufacture of bread makes use of potatoes, yeast, flour, water, salt, and stuff. A few remarks are necessary respecting each of these ingredients.

As a sack of flour weighs 280 lbs., the addition of so small a quantity of potatoes as 8 lbs. cannot be for the purpose of adulteration. It is possible that some of the cheap-bread bakers use a very much larger proportion, with a fraudulent intention, potatoes being cheaper and less nutritious than a similar weight of wheat flour. There is, however, nothing injurious to the health of the consumer in the practice, and the addition of 7 or 8 lbs. of *fruit*, as the bakers term it, to a sack of flour, is said to assist fermentation, and to improve the appearance of the bread.

A far more objectionable material is *alum*, which is used by the bakers under the name of *stuff* or *rocky*. Its object is to bleach the bread, but the manner in which it acts as a bleaching material is by no means understood. It is, however, positively stated that if it be omitted, the bread, instead of being white, is brown. The proportion of alum to a sack of flour is much less than is generally supposed; and it is even less than the bakers themselves are aware of, for as they are liable to a heavy fine if alum be found on the premises, they purchase packets of *stuff* ready prepared for them by the druggists. The bakers suppose this to be ground alum, whereas, it actually consists of 1 part alum and 3 parts of common salt. This mixture is sold in pound packets at 2*d.* each. 8 oz. of this stuff are used to a sack of flour, so that the quantity of alum is only 2 oz. to 280 lbs. of flour, a quantity too small to have any injurious effect on the health. The presence of alum also causes the loaves to break from each other with a much smoother surface than if it were absent.

It is stated that gypsum, chalk, pipe-clay, and [illegible] and white vitriol have been used to adulterate bread. These are most pernicious adulterants. Ground bones are also mentioned among the adulterants, but the reduction of bones to a powder fine enough for the purpose of adulterating flour would be more costly than the flour itself. We believe, however, that the chief adulterant of bread is in the flour itself, good flour being adulterated with an inferior flour, or with the flour of beans or peas. These, together with potatoes, are perfectly harmless. The great objection to their use is that the customer pays for them the same price as he would do for the fine flour.

Salt is a necessary article of food, and it is added to bread for the purpose of flavour. If the quantity be large, the bread retains more moisture than it otherwise would, and thus weighs heavier. But the taste of such bread sufficiently indicates its bad quality; it is rough in the grain, and two adhering loaves generally separate unevenly. The usual allowance of salt is an ounce to the quartern loaf; but the salt may be introduced by combining its constituents in the dough, for which purpose the flour is mixed up with a solution of carbonate of soda, and then a solution of muriatic acid is added. The carbonic acid thus disengaged will supersede the use of yeast, and will form, when baked, a light and excellent bread.

The usual method of fermenting bread is by means of yeast. This is obtained from the London brewers, or is manufactured for the purpose, as already noticed. Ale-brewers' yeast is well adapted to the purpose, but it cannot be obtained in sufficient quantity. The yeast of the porter-brewer is too bitter and too highly coloured to be used without a previous washing. Distillers' yeast has neither bitterness nor colour, but it is scarce. In warm climates, where yeast cannot be had, other ferments are substituted. In the East Indies bread is raised by means of a liquor called *toddy*, which flows from the cocoa-nut tree when its branches are cut. It ferments so rapidly, that in two or three hours it becomes an intoxicating liquor. In the West Indies *dunder* is used. This is a liquor remaining in the still after the distillation of rum.

The flour ought to be some weeks old before it is made into bread. A sack of flour weighing 280 lbs., and containing 5 bushels, generally produces 80 loaves. According to this, ⅕th of the loaf is water and salt, and ⅘ths flour; but the number of the loaves depends on the goodness of the flour. Good flour requires more water than bad, and old flour more than new; 82, 83, or even 86 loaves may in some cases be made out of a sack, and in other cases scarcely 80. There is a considerable loss of weight in baking, the average loss in a quartern loaf being 9½ oz., or not quite ⅐th. If we take the loaves as peck, half-peck and quartern, the following were found within 48 hours after baking to be the weights before and after putting in the oven:—

	Before.				*After.*		
	lbs.	oz.	dr.		lbs.	oz.	dr.
Peck	19	12	0	avoirdupoise.	17	6	0
Half-peck .	9	11	0	—	8	11	0
Quartern . .	4	15	0	—	4	5	8

The loaf which presents the greatest surface in the oven loses most weight.

In the time of bad harvests, when the wheat is damaged, the flour may be considerably improved, without any injurious result whatever, by the addition of from 20 to 40 grains of carbonate of magnesia to every pound of flour.

The water used in making bread ought to be of good quality. It is stated that if the flour be kneaded with water saturated with carbonic acid gas, no yeast is necessary, and that bakers who live near Selzer water springs may substitute such water for yeast.

The Bakers of London constitute the nineteenth Company. They were incorporated about the year 1307, and consist of a master, 4 wardens, 30 assistants, and liverymen, and commonalty.

An expeditious and simple method of making bread for a small family is thus described in the Guide to Trade:—Take half a bushel of flour, and put it all except about 4lbs. into a tub or pan, and in winter place it before the fire to warm. Mix 6 or 8 ounces of powdered salt with the flour, or work it in with the dough. Then take a pint of good fresh yeast, and mix it well with a sufficient quantity of water at a blood heat. Make a deep hole in the middle of the flour; pour the water and yeast gradually into it, mixing the whole together with your hands until they are well incorporated. Cover this mixture up, and place it near the fire till it is well risen. Then work the remaining flour into it with your fists till it become a nice, smooth, tough dough. Make this dough into loaves, and bake in an oven properly heated. It will take from 1½ to 2 hours in baking, but the bread should always remain in the oven half an hour after it has become brown, or it will not be *soaked* through.

For larger bakings, put the flour into a trough or tub sufficiently large to allow the dough to swell. Make a deep hole in the centre of the flour. For half a bushel of flour take a pint of thick fresh yeast (not frothy), and mix it with a pint of fresh warm water, not too hot. Then gently mix with the yeast and water as much flour as will make it into a stiff batter. Pour this mixture into the hole in the flour, and cover it by sprinkling it over with flour. Then place over it a flannel or sack, and in cold weather place it near the fire, but not too near. When the sponge has risen enough to crack the dry flour with which it is covered, sprinkle over the top 6 oz. of salt (more or less according to taste). Then work it with the rest of the flour, and add from time to time warm water till the whole is sufficiently moistened, or scarcely so moist as pie-crust. Next work it well by pushing your fists into it, then rolling it out with your hands, folding it up again, kneading it again with your fists, till it is completely mixed and formed into a stiff, tough, smooth dough. Form your dough into a lump like a large dumpling, cover it up and keep it warm. After rising for about 20 or 30 minutes, make it into loaves, having shaken a little flour over the board to prevent sticking. The loaves may be made up in tin moulds, or you may divide the dough into equal parts according to the size required, and make each part into the form of a dumpling, and lay one of these upon another, then put the loaves into the oven, and bake for 1½ or 2 hours.

In the Pharmaceutical Journal several recipes are given for making unfermented bread. In a paper by Mr. H. Deane, contained in the third volume, the following recipe, by Dr. Smith, of Leeds, is given:—

5 lbs. of flour.

½ oz. (apothecaries' weight) of sesquicarbonate of soda.

½ drachm of sesquicarbonate of ammonia.

4 drachms or teaspoonfuls of common salt.

Mix these intimately together, and then add the following solution:

50 oz., or 2½ pints, imperial, of cold water,

5 drachms of hydrochloric acid.

This bread is easily made, requires little labour, no kneading, or time for the dough to rise. It costs a trifle more than bread made with yeast, but has the advantage of keeping longer without turning mouldy or sour, and is wholly free from any bitter or unpleasant taste. Its dietetic properties are of the utmost importance. Common bread is liable in weak stomachs to turn sour, and produce heartburn and flatulency, and to aggravate cases of dyspepsia; but bread made by the new process is free from these baneful effects. Its daily use in health prevents these symptoms, and in many cases it corrects that morbid condition of the stomach and intestines on which these symptoms depend. It is useful in assisting to restore the biliary, and especially the renal, secretions to a healthy condition, as well as in the treatment of various cutaneous eruptions, originating in disorder of the digestive functions.

Mr. Deane's recipe is as follows:—

4 lbs. flour.

½ oz. (avoirdupois weight) of bicarbonate of soda.

4⅓ fluid drachms of hydrochloric acid (specific gravity 1.16).

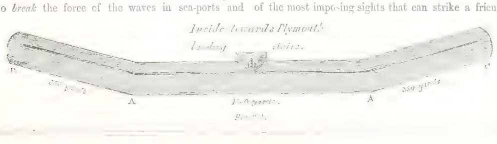
¼ oz. common salt.

40 fluid ounces, or 2 pints imperial, of cold water.

Mix the soda perfectly with the flour, and the acid with the water, then the whole intimately and speedily together, using a flat piece of wood, or spaddle, for the purpose. It may be made into 2 loaves, and put into a quick oven immediately. It will require about 1½ hour to bake.

In this kind of bread, kneading will prove injurious, by making it too heavy. The dough must not be too stiff. [See STARCH—WHEAT—and APPENDIX.]

BREAKWATER. An artificial barrier, designed to *break* the force of the waves in sea-ports and harbours, and thus to protect the shipping from serious damage. Breakwaters are of various kinds, according to the nature of the roadstead or harbour, and the number of ships resorting thereto. In some cases, the roll of the waves is sufficiently checked by sunken vessels placed across the entrance of the harbour; in others, by moles, or piers projecting from the land; but there are cases, such as that of Plymouth Sound, where a large assemblage of ships cannot find a safe place of rendezvous without an erection of far greater magnitude than these. Plymouth Breakwater presents a very remarkable instance of human skill and perseverance, successfully applied. It consists of an immense number of blocks of stone, thrown into the Sound, until a barrier nearly a mile in length was raised above the surface of the water, stretching across the Sound, and leaving entrances at both ends. This great undertaking was commenced in August 1812, and so early as the end of the second year, about eight hundred yards of the breakwater began to appear at low-water, and the swell was so much broken that ships of all sizes began to take shelter within the breakwater, and fishermen within it could not judge of the weather outside the Sound. Some limestone quarries near the Catwater were purchased of the Duke of Bedford for 10,000*l.*, and about fifteen vessels were constantly employed in conveying the masses of stone (varying in weight from one ton to ten tons) to their destined place. Many ingenious devices were employed to hasten the progress of the work, so that, during the first five years, the amount of stone deposited gradually rose from 16,000 to 300,000 tons per annum. The large masses were first lowered, and then smaller stones, quarry rubbish, rubble, and lime screenings, to fill up the cavities and form a compact mass. This structure was completed in March 1841, with the use of 3,369,261 tons of stone, and at the cost to Government of nearly a million and a half of money. The construction of this breakwater was at the time an object of the greatest interest in our own country, and to foreigners visiting us. A celebrated French engineer (Dupin) described in terms of high praise the working of the quarries, the order, regularity, and activity visible in all the operations, the embarking and disembarking of the materials, &c. "Those enormous masses of stone," he says, "which the quarrymen strike with heavy strokes of their hammers; and those aërial roads of flying bridges, which serve for the removal of the superstratum of earth; those lines of cranes, all at work at the same moment; the trucks all in motion; the arrival, the loading, and the departure of the vessels; all this forms one of the most imposing sights that can strike a friend



to the great works of art. At fixed hours the sound of a bell is heard, in order to announce the blasting of the quarry. The operations instantly cease on all sides; all becomes silence and solitude. This universal silence renders still more imposing the noise of the explosion, the splitting of the rocks, their ponderous fall, and the prolonged sound of the echoes."

The vessels employed for transporting the stone to the site of the breakwater (marked out in the sound by a line of buoys) were of a peculiar construction. They had two railways laid along them, parallel to each other, with openings in the stern, to admit the trucks laden with stones. These were wheeled from the quarry to the quay, thence to the openings in the vessel, and along the rails laid down in it, until both these lines of rail were filled with trucks. The vessel then proceeded on its way, bearing its load of trucks and stones, and, on reaching the breakwater, each truck was wheeled to the opening, where by machinery it was overset, and the stones cast into the sea. Fig. 232 shows the stern of the vessel, when loaded, with the ports up or closed; Fig. 233 shows the stern of the vessel in the act of depositing the stones. The runner being hooked to the forepart of the truck, raises it up, and tips the stone overboard. By these means a cargo of sixty or eighty tons could thus be discharged in an hour.

Fig. 232.

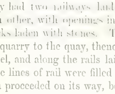
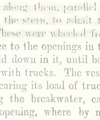


Fig. 233.



A breakwater was thus formed, having a centre 3,000 feet long, and two arms, or bends, each 1,050 feet long, inclining towards the land. At the extremity of the western arm a circular foundation was prepared, on which a lighthouse has been placed. The entrance into the harbour on this western side is the principal entrance for shipping: it is about half a mile wide, and at low water spring-tides the depth of water varies from seven to nine fathoms. The eastern entrance is of about the same width, but the depth of water is not so great, being about six or seven fathoms. The outer slope of the breakwater below the line of low-water was formed by the sea, and proves to be from three to four feet horizontal to one of perpendicular; from the low-water line upwards it is five to one. The inner slope is two feet horizontal to one perpendicular, from the base to the top, which is two feet above high-water spring-tides. When the action of the sea had formed its own slope, and had wedged together and settled the great mass of materials which forms the breakwater, and when no further movement was apparent, but the whole appeared consolidated together, then the slope towards the sea was cased with regular courses of masonry, dowelled, joggled, dove-tailed, and cramped together; the diving-bell being brought into requisition for placing the lower courses, which were of granite, and were laid horizontally on their natural beds, and dove-tailed, lewised, and bolted together.

The Plymouth breakwater is capable of affording secure and convenient anchorage to a fleet of twenty-five or thirty sail of the line; and the additional advantage of a plentiful supply of fresh water is afforded by the construction of a reservoir above Bouvisand Bay, capable of containing from ten to twelve thousand tons, or a quantity sufficient to water fifty sail of the line. This water is brought in pipes to Steddon Point, opposite the anchorage, where a jetty is thrown out, from which the water descends through the pipes to the ships' boats. The whole expense of this valuable arrangement was about 16,000*l*.

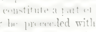
In the construction of the Plymouth breakwater, experience had been gained by the failure of a previous attempt made on the French coast at Cherbourg. Under the direction of the French government, M. de Cessart prepared a plan for a barrier in the middle of the sea, and in front of that roadstead; but, unfortunately, he adopted, as the only mode of producing smooth water, the idea of a number of large masses of a conical form, touching each other at their base, but separating upwards, and leaving alternate openings and points of resistance, which, it was thought, would effectually break down and interrupt the waves entering the harbour. It was proposed to construct these conical caissons of wood, the number of which, to cover the destined extent of 2,000 toises, would amount to 90, causing a total expense of 32,400,000 livres for the whole. The number was afterwards reduced to 64, and the estimated time for completing them was thirteen years. Each cone was to be 150 feet diameter at the base, and 60 feet diameter at the top, and from 60 to 70 feet in height; the depth of water at spring tides, in the line in which they were intended to be sunk, varying from about 56 to 70 feet. Within the exterior cone was an interior and concentric one, bound together by beams of wood. The frame of each cone was composed of 80 large upright beams, 24 feet long, and 1 foot square. On these were erected 80 more, of 14 feet in length, making in all 320 large uprights. The machine was then planked, hooped, and firmly fixed together with iron bolts. The cones were to be sunk empty, and without bottoms, and were to be filled afterwards. On the 6th of June, 1784, the first cone was floated off, and sunk, and, on the 7th July following, a second, in the presence of ten thousand spectators; but before the cavity of the latter could be filled with stones, a storm in August, continuing five days, entirely demolished the upper part of the cone. The quantity of stones sunk that summer within the cavities of the two cones, outside their bases, and in the intermediate space, amounted to about 65,000 tons. In 1785, three more cones were sunk, and in the following year, five more; but the storms of winter carried away the upper parts of those five. Three were sunk in 1788; but these met with the same fate, so that government, in disgust at the delay and expense, sold the three cones then on the building-slips for whatever they would fetch. The array of persons employed on this undertaking was enormous. M. de Cessart, in order to make, and sink, and fill five cones a-year, found it necessary to have 250 carpenters, 30 blacksmiths, 200 stone-hewers, 200 masons, and 520 general labourers. In the whole operation from first to last, there were employed from 1,200 to 1,500 artificers and labourers, and to these were added about three thousand soldiers, for a body of troops had been marched to Cherbourg on the commencement of the undertaking, that there might be no lack of labourers to carry it into effect. This affords a remarkable contrast to the small establishment employed to carry on the Plymouth breakwater. Here there were the following persons:—

	Persons
A superintendent and proper officers and clerks, to keep and control the accounts	10
Warrant-officers and masters of the ten stone vessels, in the immediate employ of the public	21
Seamen and boys to navigate these vessels	90
Seamen employed in the superintendent's vessel, the light vessel, boats' crews, &c	45
Masons, blacksmiths, carpenters, sailmakers, employed at Oreston . .	39
In the immediate pay of Government	205
Seamen employed in the contractors' vessels	170
Quarrymen, labourers, &c. employed at Oreston by the contractors . .	300
	675

The engineer of the Plymouth breakwater was Mr. Rennie, who did not live to carry through the whole of his undertaking; the lighthouse on the western extremity having been constructed from his designs by Messrs. Walker and Burgess. Among the plans rejected by Government at the time that his was adopted, was one for a floating breakwater, composed of triangular or prismatic floats of wood, held together by iron chains. These might be extended across the whole sound, because they would allow a great part of the tide to pass through them, while the whole water-way below would be left clear. Sufficient intervals were to be left between the rows of floats, as well as the contiguous floats, to allow of ships shaping their course between them; and it was not thought likely that, in the event of a ship striking against, or even running over, one of these breakwaters, it would occasion any material injury to either. A floating breakwater, on a somewhat similar plan, has since been made the subject of a patent, and its practical application undertaken by a joint-stock company.

A patent was taken out in 1848 by Mr. Beardmore, for an invention designed to facilitate the construction of breakwaters and other submarine works. It consists in the employment of a caisson or enclosure, constructed so as to float, with a portion of the structure built therein, to the spot where the breakwater is to be placed, and to constitute a part of the permanent work, which may be proceeded with to completion, with more expedition and convenience, and less liability to damage, than is usually experienced in such structures. The caisson consists of wrought iron plate bottom, sides, and ends, and occasional transverse bulk-heads, strengthened by ribs, and firmly connected together, so as to withstand pressure in every direction; the whole being so bonded together as to constitute one entire frame, of great strength, solidity, and power of resisting strains. When sunk, with its enclosed masonry, it would at once form a solid foundation and a material part of the permanent work. A transverse section of one of these caissons, with its sides filled in with stones, is shown at Fig. 234.

Fig. 234.



BREAST-WHEEL. See WATER WHEELS.

BREWING. See BEER.

BRICK. A building material, known at a very early period of the world's history, formed of tempered clay, hardened either by exposure to the sun's rays, or to the heat of a furnace. Bricks were used in the building of Babel, and it would appear that they were *burnt* bricks. ("Let us make brick, and burn them throughly. And they had brick for stone, and slime had they for mortar." Gen. xi. 3.) Also in the walls of Babylon, where the clay thrown out of the trench surrounding the city, supplied the material; and especially in the pyramids and other buildings of Egypt, where their manufacture gave employment to a vast number of persons, and at last became important enough to be undertaken by the state. Thus the public purchased of the government, and private individuals were forbidden to engage in the manufacture, or to use any bricks to which the government stamp was not affixed. The brick makers worked in gangs, under the superintendence of overseers and task-masters; the clay was worked up with chopped straw, and the bricks prepared from it were dried in the sun. The employment was laborious, and the task-masters were as exacting as in later times. (Exod. v. 6—19.) The principal pyramids of Egypt are built of stone, but several of the smaller are of brick, as that of Howara, which is constructed of crude bricks, containing chopped straw. These bricks measure 17½ inches by 8¾ inches, and are 5½ inches thick. In some cases the bricks contain not only straw, but pieces of broken pottery and stone, and are very irregular in size. A brick pyramid about ten leagues from Cairo, is supposed to be that mentioned by Herodotus, as having once borne the following inscription: "Disparage me not, by comparing me with pyramids made of stone:

I am as much superior to them as Jove is superior to the rest of the deities: I am constructed of bricks, made from mud, which adhered to the ends of poles, and was drawn up from the bottom of the lake."

Unburnt bricks were used in the walls of Athens, and in the construction of several Grecian temples and palaces. Vitruvius expressly describes the manner in which these bricks were made, and the proper seasons for drying them regularly; namely, spring and autumn. The inhabitants of Utica made use of such bricks only as were five years old, and had been approved by a magistrate.

The Romans made use of bricks to a far greater extent than the Greeks, as the remains of their public edifices plainly show: some of their brick structures raised 1,700 years ago still remain as entire as when first built. To that people, doubtless, we are indebted for the introduction of the art into Britain. But the use of brick does not appear to have become general in this country until after the Norman conquest, nor to have attained any remarkable degree of perfection until so late as the reign of Henry VIII., when many interesting buildings were constructed of this material, in a style which has made them objects of admiration in our own age. Yet it was only for the more important edifices that brick was solely used; the ordinary houses consisted of a frame-work of timber, either filled in with lath and plaster, or with bricks introduced in panels. The danger of so great use of timber in a crowded city became evident when the great fire of London desolated the homes of the metropolis, and after that event, it was wisely ordained that brick should be the material of the future city, and that even the ornamental part of the houses should be contrived in the same material. Thus, brick-work came to be carved and made to assume the forms which more properly belong to stone, such as Doric pillars, and rich entablatures curiously wrought with the chisel subsequent to the erection of the walls. In Holland the art of making very durable bricks was practised at an early period, the floors and pavements being constructed of that material. These remain uninjured for a surprising length of time, and exhibit the superior quality of the brick. English bricks are decidedly inferior to these, not on account of any defect in the materials, but on account of the saving of labour and fuel which is sought after in the majority of cases, and which is rendered necessary by the mania for cheapness. The system prevailing in the metropolis fosters this mania, for the great majority of the lands are let on building leases, and it is to the interest of the builder to erect houses which shall merely last out the lease, since, at the expiration of that period they become the property of the landlord.

The operations connected with ordinary brickmaking are briefly these: digging the clay in autumn; leaving it to mellow by frost during winter, the masses being frequently turned and broken up, to expose them more completely to the action of the atmosphere: throwing the crumbled clay in spring into shallow pits, where it is watered and soaked: then tempering the clay by treading and kneading by the feet either of men or oxen, or by means of a horsemill: next conveying the kneaded clay to the bench of the moulder, who takes a lump and dashes it into a wooden or iron mould, striking off the superfluous clay with a strike or smooth piece of wood. The bricks are delivered from the mould, and ranged on a barrow or on the ground, until they are firm enough to bear handling, when they are trimmed with a knife. They are then built up in long dwarf walls, with sufficient space for the air to penetrate in every direction: these walls are thatched as a protection from the weather, and thus the bricks are left to dry until they are in a proper state to be consigned to the kiln.

The various argillaceous earths used in brickmaking are generally mixed with some other substance, being for the most part unfit to be used alone. Some are almost pure clay or alumina, and are strong, and exceedingly plastic, but cannot be dried without splitting. Others, being light sandy clays or loams, are too loose to be made into bricks without the admixture of lime as a flux, to bind the materials together. Others again are natural compounds of alumina and silica; but these if free from lime, magnesia, or metallic oxides, are exceedingly valuable clays, being from their infusible nature adapted for making fire-bricks for lining furnaces, for making crucibles, glass-house pots, &c. Fire-clay is found throughout the coal-measures, and occurs in abundance, and of excellent quality, at Stourbridge, and also in the vicinity of Newcastle and Glasgow.

Bricks for ordinary uses are known as "place-bricks," "grey and red stocks," "marl-facing bricks," and "cutting bricks." The place-bricks and stocks are the ordinary wall bricks. The marls are very superior bricks, made in the neighbourhood of London, and used on the outside of buildings. The finest kind of marls and red bricks are called cutting bricks, and are used in arches over doors and windows, being rubbed to a centre and gauged to a height. The red bricks made of Hedgerly loam, from a village of that name, near Windsor, are used as fire-bricks about furnaces and ovens. Foreign bricks are *Dutch* and *Flemish* bricks and clinkers: they are similar in quality, and of a dirty brimstone colour. The first two are used for paving yards, stables, &c., and the clinkers which are most baked are used for ovens. Place-bricks are also used in paving dry, or laid in mortar, and they are put down flat or edgewise. If they are laid flat, 32 of them will pave a square yard; if edgewise, twice that number are required. Ventilating bricks are an invention of modern times. They are double the size of common bricks, although they contain only the same quantity of clay. They are hollowed out at the sides, so that when two are placed side by side, a circular opening is left between them, which, when tiers of similar bricks are laid on, forms of course a tube within the wall, and this may be applied to the purpose of either warming or ventilation.

The first process in brick making is the tempering of the clay, which, as we have said, is the work of early spring, after it has lain exposed to the frost during winter. Great care is then taken as the clay is being turned over and tempered with water, to remove by hand every stone that can be discovered in the plastic mass; for the presence of even a small pebble in a brick causes it to crack in drying. Of course this hand-picking is impossible where much gravel occurs: in such cases the clay must be washed in a trough filled with water, until it becomes liquid enough to pass off through a grating into pits prepared for its reception; the gravel meanwhile being retained by the grating. In districts where veins of skerry or impure limestone abound, it is found desirable to grind the clay between rollers, which crush the limestone, and thus obviate the evil which arises when even a small piece of this substance remains in a brick, and by the carbonic acid driven off from it in burning, forces a hole in the brick, and destroys its usefulness.

For the marl, or *malm* bricks, made near London, and used for the best outside work in houses, the clay is dug in autumn, ground to a pulp at once in a wash-mill, and mixed with chalk previously ground to the consistence of cream. This pulp is run off through gratings, and allowed to settle until it is firm enough for a man to walk upon it: it is then covered with finely-sifted ashes, and allowed to remain all the winter to mellow. In the spring the ashes are thoroughly mixed with the clay and pugged in a pug mill This is a conical wooden tub, having the larger end upwards, with an upright revolving shaft passing through it, armed with a number of knives, which cut and knead the clay, and force it through the mill, which is constantly filled at the top from the barrows of the work-people, while the clay continually issues from a hole in the bottom, where it is cut into convenient pieces and piled up for future use. The pug-mill is extensively used where the demand for bricks is large, and where the brick-earth is favourable in quality; but in many country places, the indispensable labour of kneading the clay is still performed by the treading of men's naked feet, which become by constant practice sensitive to the slightest roughness in the mass, and able to detect the smallest stone or impurity.

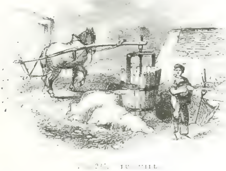
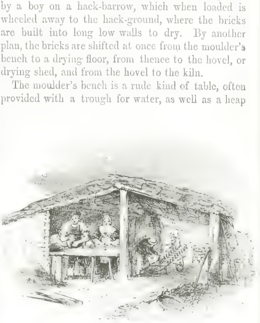


FIG. 235.—PUG MILL.

When the clay has been reduced by one of these processes to the necessary state for brick-making, masses of it are successively brought to the moulder's bench. The mould is without top or bottom, and the workman's art consists in dashing a piece of clay with such force into it, as completely to fill it, and then cleverly striking off the superfluous quantity, and turning out the brick on a pallet, which is placed by a boy on a hack-barrow, which when loaded is wheeled away to the hack-ground, where the bricks are built into long low walls to dry. By another plan, the bricks are shifted at once from the moulder's bench to a drying floor, from thence to the hovel, or drying shed, and from the hovel to the kiln.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The moulder's bench is a rude kind of table, often provided with a trough for water, as well as a heap of sand, the mould being either dipped in water, or sanded, between the making of each brick, that the clay may not adhere. If water is used, the process is commonly called *slop-moulding*; if sand, *pallet-moulding*. In the neighbourhood of London, women commonly take part in the operations. Fig. 236 represents a woman thus engaged. The moulds were formerly of wood only; they are now sometimes made of brass, cast in four pieces, and riveted together, or of wood lined with brass, sometimes of wood with the edges of iron, sometimes with the two longest sides of iron. Brass moulds do not require wetting or sanding; but they are expensive, and the edges soon become worn. Wooden moulds therefore continue in some districts to be largely used. A good form of mould is a wooden mould lined with brass; the wood as well as the brass being in four pieces, and attached by rivets at the angles. This mould costs about twenty-five shillings, and was formerly still more expensive. The brass overlaps the wood at the edges, where it wears out rapidly, and the cost of repair is nearly as much as the original price of the mould. Fig. 237 represents a mould made of sheet-iron in four pieces, riveted at the angles, and strengthened with wood at the sides.

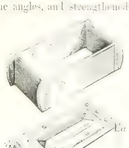


Fig. 237.

The bottom is separate, and is called a *stock-board*. This is fastened by pins at the corners to the moulder's bench. It is very common at the present time to make bricks with a hollow underneath, both for the sake of lightness, and to leave a bed for the mortar. This is managed by fastening a piece of wood called a *kick* to the upper side of the stock-board. The mould being placed on the stock-board, (which easily and accurately fits it,) and the clay pressed into the mould, a hollow space corresponding to this kick is of course formed on the under side of the brick. The pallets are pieces of board $\frac{3}{8}$ths of an inch thick, of the same width as the mould, but a little longer. Six-and-twenty pallets form a set, and three sets are required for each moulder. Fig. 238

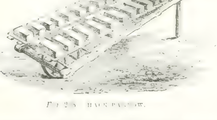


Fig. 238.—HACK-BARROW.

represents the bricks on one set of pallets, ranged on the *hack-barrow*, which has a flat top of light framework, fit to receive two rows of bricks, thirteen in each row. Three of these barrows are required for use at each moulder's bench, one being constantly loading there, another unloading in the drying ground, and the third being wheeled to and fro. The low walls of bricks in the drying ground are called *hacks*. These are built two bricks wide, and eight bricks high, and the bricks are generally placed slanting, and not at right angles to the length of the wall. When the bottom row of one hack is formed, the workman begins a second hack, leaving the first to get firm before it has to bear the weight of a second row. Plenty of straw or hay is at hand to cover up the bricks at night, or in bad weather. For the finer descriptions of bricks, drying under cover is adopted, and in some instances flues are carried under the floors of the drying sheds, and currents of air are carefully excluded.

Where the demand for bricks is very large, brick-moulding is performed by machinery. A number of machines have been invented for this purpose, and some of them have answered the end very well. But it is doubtful whether the pressure employed is really an advantage. The density of the bricks is thereby increased, and they are smoother, heavier, and stronger than other bricks, which for some purposes is desirable, but they do not adhere so well to the mortar, they are difficult to dry well, and their weight adds to the expense of carriage, and prevents the workman from laying so many in a given time, as of the hand-made bricks. Machine-made bricks are also frequently disfigured by a ridge caused by the clay rising a little way up the sides of the piston, in the space which, without careful workmanship, is apt to occur between the piston and the mould.

Two brickmaking machines much in favour in this country are Ainslie's and Hunt's. The latter has been extensively used in the execution of large contracts, and consists of two cylinders, each covered with an endless web, which are so placed that they form a sort of hopper on their two upper cylindrical surfaces, the ends being enclosed by two iron plates. The tempered clay is thrown into this hopper, and at the lower part it acquires the form and dimensions of a brick. Beneath is worked an endless chain, by the movement of the cylinders, and at various marked intervals are laid the pallet-boards under the hopper; the clay is brought down by a slight pressure, and enters a frame, which has a wire stretched across it, which projects through the mass, and cuts off the requisite thickness; this is immediately removed by the forward motion of the endless chain; and this operation is renewed as often as a new pallet-board is advanced under the hopper. Such a machine produces about 1,200 bricks per hour, and is worked by two men and three boys. By this plan less pressure is given than in most machines, consequently the bricks are less difficult to dry equally. Machine work is cheaper than hand-labour in the moulding of bricks.

Machinery has been recently employed for making bricks and other articles of clay nearly in the state of a dry powder. The clay is subjected to heavy pressure in strong metal moulds, and is by this means reduced to one-third its original thickness. It retains just sufficient moisture to give it cohesion, and the bricks thus formed can be handled at once, and taken direct to the kiln. This method was devised by Mr. Prosser of Birmingham, and is highly useful for making ornamental bricks, floor-tiles, &c. By an experiment made on a nine-inch brick of this sort, it was found that the resistance to a crushing force is immense, ninety tons having been sustained without injury.

The final process in brick-making is that of burning the bricks in a kiln or in clamps, the former being the old and the best plan. The kiln may be a simple rectangular chamber, built of old bricks and rubble stone, with a narrow doorway at each end, and narrow fire-holes lined with fire-bricks in the side walls exactly opposite each other. The workmen introduce through the doorways a quantity of bricks, and stack them loosely but with considerable art in cross courses, within the walls, leaving openings that shall act as flues throughout the whole mass, and thus distribute the heat from top to bottom. When the kiln is filled, the top is covered in, and fires are lighted in the fire-holes. The fire is at first got up gently, that the moisture in the bricks may be gradually evaporated; but in two or three days, when the steam ceases to rise, the heat is raised, the doorways are bricked up, and the temperature continued till the fire begins to appear at the top. It is then slackened, and the kiln allowed to cool. The heating and cooling are then repeated, and in about 48 hours the bricks are thoroughly burnt. An ordinary kiln will hold 20,000 bricks. The fuel consists in some places of fagots of furze, heath, brake, &c., in others of pit coals. When bricks are burnt in a clamp, they afford to a great extent their own fuel, for a clamp is an immense pile of carefully arranged bricks, in which *breeze*, (the technical name for ashes,) has been mixed with the clay in their manufacture. But layers of breeze are also added, and the whole is set fire to by means of fireplaces and flues filled with wood, coal, and breeze. The burning of a clamp continues from two to six weeks. The art of clamping well exhibits no mean degree of skill in the workman. They first build an *upright* or double battering wall along the centre, and then arrange a number of other walls in an inclined position on each side, corresponding in length and height with the central wall, and supported by it. The sides and top of the clamp are cased with burnt brick, and the lower courses of the central double wall are of the same material. There are numerous live-holes left in a large clamp, and these are fired in succession. The bricks near these live-holes are burnt too much, and generally spoiled by running together in masses called burrs, and the bricks at the outside of the clamp are not burnt enough, and are laid aside for re-burning in the next clamp. Much judgment is required in apportioning the fuel to the size of the clamp, for the whole may be easily underburned or overburned, and so deteriorated or rendered comparatively useless. The burrs and clinkers, or shapeless masses of fused brick, may often be recognised in the rock-work of suburban gardens, while the pale underbaked bricks, sold at low price, are used in the inferior unsubstantial erections which disgrace the neighbourhood of the metropolis.

The processes above described are not universally prevalent. On the contrary, various differences exist in particular districts. These are well indicated in the following paragraph from Dobson's clever Treatise on "Brick and Tile-making."(1) "In some districts the clay is ground between rollers, and the pug-mill is never used. In others both rollers and pug-mills are employed. In the neighbourhood of London rollers are unknown, and the clay is passed through a wash-mill. Equal differences exist in the processes of moulding and drying. Lastly, the form of the kiln varies greatly. In many places the common Dutch kiln is the one employed. In Essex and Suffolk the kilns have arched furnaces beneath their floors. In Staffordshire, bricks are fired in circular domed ovens called cupolas."

At the close of the last century, bricks were for the first time subjected to taxation. A duty of 2s. 6d. per thousand was imposed on all bricks, and this was afterwards raised to 4s. per thousand. Subsequently, bricks were divided into common and dressed, and separate duties were laid upon each. In 1833, the duties on tiles were wholly repealed, but those on bricks still remained, and were raised two years later, so that common bricks paid 5s. 10d. per thousand, and superior ones a higher rate. In 1839, the duty of 5s. 10d. was made general on all bricks, without distinction of shape or quality, and this was felt as a boon, because the restrictions had previously limited the manufacture of various patterns. It was also enacted that bricks used in draining marshy land should be exempt from duty, provided the word "Drain" was legibly stamped upon them. Bricks made in Ireland, and also bricks for exportation, were never subjected to duty, but with respect to the latter, sufficient security was required before shipment that they should not be relanded in England, and if it was discovered that this was done, the owner had to suffer, over and above the penalty in his bond, the forfeiture of the whole cargo. By a recent act, the duty on bricks was wholly repealed. Notwithstanding the influence of the duty, the number of bricks made in England has nearly doubled during the twenty years ending with 1840, the number that paid duty in 1821 having been 899,178,510, whereas in 1840, it amounted to 1,677,811,131; and the latest accounts make it nearly 1,800,000,000, which produced an annual revenue approaching 600,000*l.* The manufacture of bricks in Scotland is limited on account of the extensive use of stone. [See POTTERY and PORCELAIN, Sec. III.; also APPENDIX.]

BRICKLAYING is the art of building with bricks, or of uniting them by cement or mortar into various forms. Bricks of English make are commonly of one form, 9 inches long, 4½ broad, and 2½ deep. They vary greatly in quality, according to the quality of the material, the manner in which the clay is tempered, and the method of burning.

The bricklayer, who is always assisted by a labourer, to supply him with bricks, mortar, &c., executes his work by the aid of a few simple tools. These are:—1. A *brick trowel*, made of well-tempered steel, Fig. 239, for taking up and spreading the mortar, and also for cutting bricks by percussion to any required size; 2. A *hammer*, Fig. 240, for cutting holes and chases in

Fig. 239.

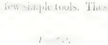


Fig. 240.

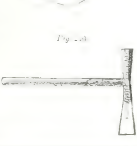
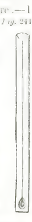


Fig. 241.



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(1) Weale's Rudimentary Series.

brick-work, and for driving or dividing bricks: to adapt it to these different uses, one end is formed like a common hammer, and the other is furnished with a kind of axe; 3. The *plumb-rule*, Fig. 241, which is a thin rule, six or seven inches wide, with a line and plummet swinging in the middle: its use is to guide the bricklayer in carrying up his walls perpendicularly; 4. The *level*, Fig. 242, which is ten or twelve feet long, with a vertical rule attached to it, in which a line and plummet are suspended: its use is to try the level of the walls at various stages of the building, as it proceeds, and particularly at the window-sills and wall-plates; 5. The *large square*, for setting out the sides of a building at right angles; 6. The *rod*, for measuring lengths, usually five or ten feet long; 7. The *jointing rule*, about eight or ten feet long, and four inches broad, with which the bricklayers *run*, or mark, the centre of each joint of the brickwork; 8. The *jointer*, Fig. 243, an iron tool, shaped like the letter S: it is used with the jointing-rule for marking the joints; 9. The *compasses*, for traversing arches and vaults; 10. The *raker*, Fig. 244, a piece of iron, having two knees, or angles, the points of which are used for raking out decayed mortar from the joints of old walls, for the purpose of replacing it with new mortar, or, as it is called, *pointing* them; 11. The *hod*, a wooden trough, shut close across at one end, and open at the other: the sides consist of two boards at right angles to each other, with a long handle projecting downwards from the middle of the angular ridge formed by the meeting of the two sides; this ridge is also partly covered by a cushion of leather, stuffed with wool, to prevent it from cutting the shoulder of the labourer. The hod is used by the labourer for conveying bricks and mortar to the bricklayer. To prevent the mortar from sticking, dry sand is strewed on the inside; 12. The *line-pins*, Fig. 245, which are of iron, for fastening and stretching the line at proper intervals of the wall, that each course may be kept straight in the face and level on the bed: the pins have a line attached to them, of sixty feet to each pin; 13. The *rammer*, similar to that of paviours: it is used for trying the ground, as well as for beating it solid, before building; 14. The *iron crow* and *pickaxe*, for breaking and cutting through walls, or moving heavy weights.

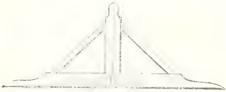


Fig. 242.

Fig. 243.

Fig. 244.

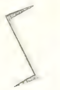
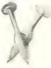


Fig. 245.



A *grinding-stone* is also used for sharpening axes, hammers, and other tools.

In the preparation and cutting of gauged arches, the following articles are used: 15. The *banker*, Fig. 246, a bench from 6 to 12 feet long, from 2½ to 3 feet wide, and about 2¾ feet high: its use is for preparing the bricks for rubbed arches, and for other gauged work; 16. The *camber slip*, Fig. 247, a piece of wood about half an inch thick, with at least one curved edge, rising about one inch in six feet, for drawing the soffit line of straight arches. When the lower edge is curved, it rises about half that of the other, or about half an inch in six feet, for the purpose of drawing the upper line of the arch, so as to prevent it becoming hollow by the settling of the arch. The upper edge is not always cambered, some preferring it straight. The slip being sufficiently long, it answers the width of many openings; and when the bricklayer has drawn his arch, he delivers it to the carpenter, to prepare the centre for it; 17. The *rubbing-stone* is a rough-grained stone, about twenty inches diameter, or less. It is fixed upon one end of the banker, Fig. 246, upon a bed of mortar. After the bricks for the gauged work have been rough-shaped by the axe, they are rubbed smooth on the rubbing-stone. The headers and stretchers, in return, which are not axed, are called *rubbed returns*, and *rubbed headers* and *stretchers*; 18. The *bedding-stone*, a straight piece of marble, eighteen or twenty inches long, of any thickness, and about eight or ten inches wide. Its use is to try the rubbed side of a brick, which must be first squared, to prove whether its surface be straight, so as to fit it upon the leading *skew back* or leading end of the arch; 19. The *square*, for trying the bedding of the bricks, and squaring the soffits across the breadth of the bricks; 20. The *bevel*, Fig. 248, for drawing the soffit line on the face of the bricks; 21. The *mould*, for forming the face and back of the brick, in order to reduce it in thickness to its proper taper, one edge of the mould being brought close to the bed of the brick when squared. The mould has a notch for every course of the arch; 22. The *scribe*, a spike or large nail, ground to a sharp point, to mark the bricks on the face and back by the tapering edges of the mould, for the purpose of cutting them; 23. The *tin saw* used for cutting the soffit lines about

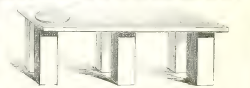
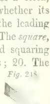


Fig. 246.

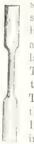
Fig. 247.

Fig. 248.



one-eighth of an inch kept by the edge of the level, on the face of the brick, then, by the edge of the square, on the bed of the brick, in order to enter the brick-axe, and to keep the brick from spalting. The saw is also used for cutting the soffit through its breadth, in the direction of the tapering lines drawn upon the face and back edge of the brick, and also for cutting the false joints of headers and stretchers; 24. The *brick-axe*, Fig. 249, for axing off the soffits of bricks to the saw cuttings, and the sides to the lines drawn by the scribes. The bricks being always rubbed smooth after axing, the more truly they are axed, the less labour will be required in rubbing them; 25. The *templet*, used for taking the length of the stretcher and width of the header; 26 The *chopping-block*, for reducing bricks to their intended size and form, by axing them. It is a piece of rough wood, six or eight inches square, supported on two fourteen-inch brick piers; but it varies in size according to the number of men working at it; 27. The *float-stone*, used for rubbing curved work smooth, such as the cylindrical backs and spherical heads of niches, to take out the axe marks. It is previously brought into a form the reverse of the surface to which it is applied.

Fig. 249



In the raising of brick walls, it is of great importance to secure a good foundation. Trenches are dug for foundations, and the ground is tried with a crowbar or rammer, to ascertain its soundness. If it appear to shake, it must be bored with a well-sinker's tool, to ascertain whether the shaking be local or general. If the soil be firm, the looser parts, if not very deep, are dug up, until the solid bed is got at. If the ground be not very loose, it may be made good by ramming into it large stones, closely packed together; but if the ground be very bad, it must be piled and planked, and in such cases, concrete is of very great service. In rising ground, the foundation must be made to rise in a series of steps. When the ground is loose in places over which it is intended to make windows, doors, &c., while the ground at the sides on which the piers are to stand is firm, it is usual to turn inverted arches over such intended openings, Fig. 250. This is a necessary precaution in all cases where the depth of the wall below will admit of it; for the piers in settling will carry the arch with them, and, by compressing the ground, assist in securing the structure. These arches should be turned with great exactness, and their height should be at least half their width. The bed of the piers ought to be as uniform as possible, for, although the bottom of the trench may be very firm, yet, if it vary in firmness, the piers will settle more in one place than in another, and thus occasion a vertical fracture in the superstructure. Should the solid parts of the trench be under the intended openings, and the softer parts where piers are to be built, on firm ground, arches, not inverted, must be suspended between them; in which case, attention must be paid to the insisting pier, whether it will cover the arch or not; for if the middle of the pier rest over the middle of the summit of the arch, the narrower the pier, the greater should be the curvature of the arch at its apex. When suspended arches are used, the intrados ought to be clear, that the arch may have its full effect. Here, also, the ground on which the piers are erected must be of equal firmness, lest the building be injured by unequal settling, which is much more mischievous than where the ground, from being uniformly soft, allows the piers to descend equally, in which case the building is seldom or never damaged.

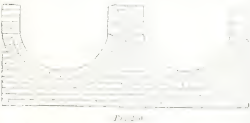


Fig. 250

In ramming foundations, the stones, previously chopped or hammered, should be laid of a breadth proportionate to the weight intended to rest on them, and rammed closely together with a heavy rammer. The lower bed of stones may in general project about a foot on each side of the wall: on this another course may be laid, so as to bring the upper bed of stone upon a general level with that of the trench, projecting about eight inches on either side of the wall, or receding four inches on each side within the lower course. The joints of every upper course must fall as nearly as possible on the middle of the stones in the course immediately beneath it; a rule to be strictly attended to in every kind of walling; for in all the modes of laying stones or bricks, the object is to obtain the greatest lap one upon the other.

In slacking the lime for preparing the mortar for the wall, no more water should be used than is barely sufficient to reduce it to powder, and it should be covered with a layer of sand to exclude the air. It is best to slack the lime in small quantities, about a bushel at a time. When the mortar is about to be used, it should be beaten three or four times, and turned over with the beater, so as to incorporate the lime and sand, a little water being added. In hot and dry weather the mortar may be made much softer than in winter. In dry weather, and for fine work, the bricks should be wetted or dipped in water as they are laid; a precaution not required in damp weather. This wetting causes the bricks to adhere to the mortar, which they will not do if laid dry and covered with sand or dust, in which case they may often be removed without any mortar adhering to them. In working up the wall, not more than four or five feet of any part should be built at a time; for, as all walls shrink directly after building, the part which is first raised will settle before the adjacent part is brought up to it, and the shrinking of the latter will cause the two parts to separate. Unless it be for the accommodation of the carpenter, no part of a wall ought to be carried higher than one scaffold without having the contingent parts added to it. In carrying up any particular part, the ends should be regularly sloped off, so as to receive the bond of the adjoining parts on the right and left.

The strength of brickwork depends on the manner in which the bricks are laid. The practice in England is confined to what is called *Old English bond* and *Flemish bond*. In English bond, Fig. 251, a row of bricks, laid lengthwise on the length of the wall, is crossed by a row with its breadth in this length, and so on alternately. The courses in which the lengths of the bricks are disposed through the length of the wall, are called *stretching courses*, and the bricks *stretchers*. The courses in which the lengths of the bricks run in the thickness of the walls, are called *heading courses*, and the bricks *headers*. Flemish bond, Fig. 252, which was introduced into England about the reign of William and Mary, consists in placing a header and a stretcher alternately in the same course. The effect is more pleasing than the former, but this mode does not produce so strong a wall. The face of an upright wall in English bond is shown in Fig. 253, and that of Flemish bond in Fig. 254.

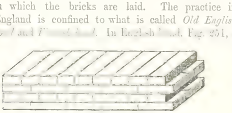


Fig. 251.

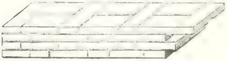


Fig. 252.

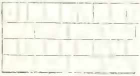


Fig. 253.

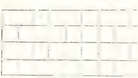


Fig. 254.

Fig. 255 is English bond in a nine-inch walling. Mr. Nicholson remarks that, as the length of a brick is nine inches, and its breadth 4½, it is usual, to prevent two vertical joints from running over each other, at the end of the first stretcher from the corner, to place the return corner stretcher, which becomes a header in the face that the stretcher is in below, and occupies half its length; a quarter brick is placed on inside, so that the two together extend 6¾ inches, leaving a lap of 2¼ inches for the next header, which lies with its middle upon the middle of the header below, and forms a continuation of the bond. The three-quarter bat thus introduced is called a *closer*. A similar effect might be obtained by introducing a three-quarter bat at the corner of the stretching course, and then the corner header being laid over it, a lap of 2¼ inches will be left at the end of the stretchers below for the next header, which being laid, the joint below the stretchers will coincide with its middle, and thus form the bond.

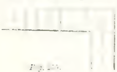


Fig. 255.

In a fourteen-inch, or brick-and-a-half wall, Fig. 256, the stretching-course upon one side is laid so that the middle of the breadth of the bricks upon the opposite side falls alternately upon the middle of the stretchers and upon the joints between the stretchers.

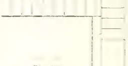


Fig. 256.

In a two-brick wall, Fig. 257, every alternate header in the heading-course is only half a brick thick on both sides, which breaks the joints in the core of the wall.

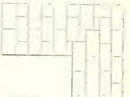


Fig. 257.

In a two-and-a-half brick wall, Fig. 258, the bricks are laid as shown in Fig. 259.

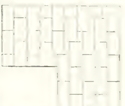


Fig. 258.

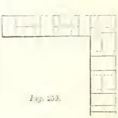


Fig. 259.

Flemish bond for a nine-inch wall is shown in Fig. 260, where two stretchers lie between two headers; the length of the headers and the breadth of the stretchers extending the whole thickness of the wall.

In brick-and-a-half Flemish bond, one side is laid as in Fig. 260, and the opposite side with a half-header opposite to the middle of the stretcher, and the middle of the stretcher opposite the middle of the end of the header.

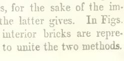


Fig. 260.

The adoption of Flemish bond leads to the frequent splitting of walls; and to prevent it, laths, or slips of hoop-iron, are sometimes laid in the horizontal joints between the two courses. Others have laid diagonal courses of bricks at certain heights from each other. Attempts have also been made to unite complete bond with Flemish facings, for the sake of the improved appearance which the latter gives. In Figs. 261, 262, 263, 264, the interior bricks are represented as disposed so as to unite the two methods.

the Flemish facings being on one side of the wall only; but this arrangement is difficult to execute, as

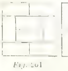


Fig. 201

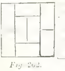


Fig. 202.

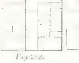


Fig. 203.

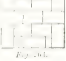


Fig. 204.

the adjustment of the bricks in one course must depend upon the course beneath, which must be recollected by the bricklayer after he has covered the course with mortar. Even should he keep his attention thus alive, the work is not so strong as English bond, which, if executed with the same attention and neatness as is required by the Flemish, would be equally handsome in appearance.

Mr. Nicholson gives the following rules for forming English bond:—1. Each course is to be formed of headers and stretchers alternately; 2. Every brick in the same course must be laid in the same direction; but in no instance is a brick to be placed with its whole length alongside of another; but to be so situated that the end of one may reach to the middle of the others which lie contiguous to it, excepting the outside of the stretching-course, where three-quarter bricks necessarily occur at the ends, to prevent a continued upright joint in the face-work; 3. A wall which crosses at a right angle with another will have all the bricks of the same level course in the same parallel direction, which completely bonds the angles, as shown by some of the preceding Figures.

In building a wall, bricks should incline slightly towards the middle of the wall, that one-half of the wall may act as a shore to the other. It was formerly the practice to build pieces of timber, called *bond timbers*, into the wall, running through its whole length, in order to add to its strength. This method of building walls is objectionable, because if the timber should decay, the wall may fail before any one is aware of the cause of failure. This method of bonding is now almost entirely superseded by the *hoop-iron* bond, which consists in laying hoop-iron flatwise between the courses. The iron should be slightly rusted, by which its adhesion to the mortar is greatly increased.

In winter it is important to preserve the unfinished wall as much as possible from the alternate effects of rain and frost, the one penetrating into the materials, and the other converting the water into ice, which by its expansion bursts, and crumbles the materials. The unfinished wall must therefore be covered with straw, or with a weather boarding in the form of a stone coping, with a body of straw under the wood.

Brick-work is measured by the *rod*. A rod of brick-work taken from the original standard of 16½ feet square, contained in the superficial rod 272¼ square feet, but as the quarter was found troublesome in calculation, 272 superficial feet came to be the standard for brick-work. The standard thickness of a brick wall is one and a half brick in length, so that if 272 square feet be multiplied by 13½ inches, the result is 306 cubic feet in the rod. A rod of standard brick-work with mortar, will require 4,500 bricks on an average, allowing for waste, this number depending on the closeness of the joints, and the size of the bricks. The mortar in a rod of brick-work will require 1½ cwt. of chalk lime, or 1 cwt. of stone lime, and 2½ loads of sand with stone lime or 2 loads with chalk lime. The weight of a rod of brick containing 4,500 stock bricks, 27 bushels of chalk lime, and 3 single loads of drift sand, is about 13 tons.

The bricklayer's labourer is paid at the rate of two thirds of the bricklayer's wages per day. One labourer is sufficient for a bricklayer when on the ground, but as the work advances in height, more may be required. In common walls, where there are few or no interruptions by apertures or recesses, the bricklayer will lay 1,000 bricks in one day, or complete a rod in about 4½ days.

There is a method of constructing a wall with a row of posts or quarters 3 feet apart, the intervals of which are filled up with brick-work. This is called *brick-nogging*. It is seldom more than the width of a brick in thickness, and should not be used where thickness can be obtained for a nine-inch wall.

After a wall is built, the joints of the bricks on the face are sometimes filled up with mortar, so as to present a regular and neat appearance. This is called *pointing*, and is of two kinds, in both of which the mortar in the joints is well raked out, and filled up again with blue mortar; but in one kind, called *flat-joint pointing*, the courses are simply marked with the edge of a trowel. If in addition to this, plaster be inserted in the joints with a regular projection, and neatly pared to a parallel breadth, this is called *tuck-pointing* or *tuck-joint pointing*.

Groined arches are sometimes made of brick. A groin is the angular curve formed by the intersection of two semi-cylinders or arches. They are raised on centres formed of carpentry work. The turning of a simple arch on a centre requires only care to keep the courses as close as possible, and to avoid the use of much mortar on the inner part of the joints. The difficulty of executing a brick groin arises from the peculiar mode of making proper bond at the intersection of the two circles as they gradually rise to the crown, where they form an exact point. In the meeting or intersecting of these angles, the inner rib should be perfectly straight and perpendicular to a diagonal line drawn on the plan. After the centres are set, the application of the brick to the angle will show in what direction it is to be cut. The sides are turned as in common cylindric vaults.

A variety of ornamental brick cornices may be formed by cutting and changing the position of the bricks employed. Others may be formed by chamfering only.

Niches in brick-work form the most difficult part of the bricklayer's art. The difficulty arises from the thinness to which the brick must be reduced at the inner circle, as they cannot extend beyond the thickness of one brick at the crown or top, it being usual as well as neatest to make all the courses standing.

The chief authority in this article has been Nicholson's New Practical Builder, London, 1823. One of the earliest treatises on Bricklaying is contained in the "Mechanick's Exercises on the doctrine of Handyworks," by Joseph Moxon, third Edition, London, 1703. The Author in his Preface seems to think an apology necessary for writing on such humble subjects as "Bricklayery;" but he says:—"I see no more reason why the sordidness of some workmen should be the cause of contempt upon manual operations, than that the excellent invention of a mill should be despised because a blind horse draws in it."

BRIDGE. An elevated construction upon or over a depression, and between depressed points, probably derived from the word *ridge*, with the prefix *be*. Professor Hosking defines a bridge as "a constructed platform, supported at intervals or at remote points, for the purpose of a road-way over a strait, an inlet or arm of the sea, a river, or other stream of water, a canal, a valley, or other depression, and over another road; distinguished from a causeway, or embanked or other continuously-supported road-way, and from a raft, by being so borne at intervals or at remote points."[1] Aqueducts, for conveying streams of water or canals, and viaducts, for carrying roads or railways, upon the same, or nearly the same, level, over depressions, are practically considered as bridges.

One of the most important requisites in a bridge is permanence. It ought to form a portion of the solid road which it connects, so as to combine comparative ease of approach with convenience of passage and agreeableness of design. The whole depression or valley must practically be obliterated in its effect upon the road, by means of the bridge passing from one summit to the other, so that the ordinary traffic may be carried on without interruption. The bridge must also afford facility of passage under it, not only for the stream, but also for the commerce of men and merchandise which are borne along upon the waters.

But a bridge is not limited to one particular form, size, proportion, material, mode of construction, arrangement, or design, but is such as circumstances require it to be. Where a stream or body of water occurs in the line of a great public road, so as to interrupt its continuity, some kind of bridge is necessary. In a river, estuary, strait, or arm of the sea, where the banks are wide and low, and where the navigation for vessels with lofty rigging is to be kept free, an ordinary bridge may be impossible, and a floating bridge, such as a passage-raft, or punt, may be all that can be allowed. For example, the great mail-road from the metropolis, through Bristol, into South Wales, is intercepted by the Severn: the river is wide; its banks are low; the water is sufficient for marine navigation, and the trade of the country requires that its course should remain open for that purpose. Hence, the erection of a bridge is prohibited. But where the banks are high, and the channel comparatively narrow, a bridge may be thrown over, as in the case of the Wear, at Bishop's Wearmouth, by Sunderland. So, also, the Straits of the Menai are passed over by the great Holyhead road, without impeding the passage of ships through the straits.

In treating of so extensive and complicated a subject as that of bridges, the literature of which forms a library in itself, it will be desirable to divide it into sections, by bringing together, *first*, a few notes on the History of Bridges, chiefly of stone; *secondly*, some details respecting the Theory of Bridges; *thirdly*, the Practice of Bridge-building; *fourthly*, Timber-bridges; *fifthly*, Suspension-bridges; and *lastly*, Iron, Girder, and Tubular-bridges.

Section I.—Historical Notice of Bridges.

The art of bridge-building, like all other useful arts, was of slow growth, and has shared in all the varied changes of man's social position at different periods of his history. In a rude state of society, the most obvious and simple bridge is a tree thrown across a stream; or, if the breadth of the stream be too great to be spanned by a single tree, a tree on each side of the stream bent down, and the branches twisted together in the middle. Mungo Park observed this method on the rivers in the interior of Africa. Another step in advance is to stretch across a river a number of ropes, made of rushes or leathern thongs, secured on the opposite banks between trees and posts, and connected and covered, so as to form a slight bridge. This method is practised in some of the mountainous districts of South America. The ropes are formed of thongs of ox-hide, consisting of several strands, about six or eight inches in thickness, and across these, in a transverse direction, sticks are laid, and these are covered with a flooring of branches of trees. In other cases, an ox-hide rope is extended from one side of the river to the other, and is secured to each bank by means of strong posts. On one side is a kind of wheel, or winch, to straighten or slacken the rope, from which hangs, by a clue at each end, a kind of leathern hammock, capable of holding a man. A rope fastened to either clue, and extended to each side of the river, is used for drawing the hammock to the side intended. A push at its first setting-off sends it quickly to the other side. Mules are carried over in this way.

Another mode of bridge-building is to construct piers of stone, at a short distance from each other, to be spanned by single stones or slabs, or by beams of timber. When this kind of bridge is used for shallow streams, and is composed of rough stones, without mortar, the operation is simple; but in deep and rapid streams, the construction of piers of hewn stone indicates a considerable advance in the useful arts, because a proper foundation for each pier is required. The bridge over the Euphrates at Babylon

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(1) "The Theory, Practice, and Architecture of Bridges of Stone, Iron, Timber, and Wire; with Examples on the principle of Suspension: Illustrated by 138 Engravings, and 92 Wood-cuts." Weale: London. 1843.

was thus formed, and this method of construction is common in different parts of China.

In that singularly interesting country, also, the arch—that grand feature in a bridge—has been in use for many ages; but the Chinese—in many cases, at least—do not seem to have constructed arched bridges of sufficient strength to bear carriages. The arch, however, covers the gateways in the great wall; and Kircher speaks of stone bridges in China, three and four miles long, and of an arch of the incredible span of six hundred feet. In Egypt and India the arch does not seem to have been known, or applied to the construction of a bridge; for although brick arches are said to have been found buried in the tombs of Thebes, yet the ancient Egyptians never built a permanent bridge across the Nile. There is no trace of the arch in the ancient works of Persia or Phœnicia; and even the Greeks, who created a school of architecture and sculpture, have a very doubtful claim to the knowledge of the arch. When Pericles adorned the city of Athens with splendid edifices, a stone bridge was not constructed over the small river Cephisus, although upon the most frequented road to that city. It is to the Romans that the western world is indebted for this useful invention. There is great uncertainty as to the time when the Romans first used the arch. If the *cloacæ* of Rome were constructed in the time of the elder Tarquin, the use of arches must have been then well known. Some writers suppose that the Romans derived their knowledge of the arch from the Tuscans, a colony of Dorians, and hence intimately connected with Greece. Some of the ancient Roman bridges still exist. (See Fig. 265.) One of the most magnificent was built by Augustus, near Narni, on the road from Rome to Loretto. It consisted of four arches, the first of 75 feet span, and 102 feet height: the spans of the other arches were 135, 114, and 142 feet, respectively. In the provinces, the Romans built many magnificent bridges. The bridge of Merida, on the river Guadiana, is said to have been 1,300 paces long, with 64 arches. But, perhaps, the most magnificent of all the Roman bridges, and one of the noblest monuments of antiquity, is the bridge of Alcantara, on the Tagus, consisting of 6 arches: the whole length is 670 Spanish feet, and the height, from the bed of the river to the roadway, is 205 feet.

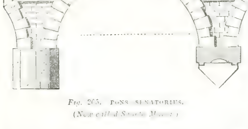

Fig. 265. PONS SENATORIUS.
(*Now called Santa Maria.*)

From the destruction of the Roman empire to the establishment of modern Europe, there are no bridges of importance, except those fine works by the Moors in Spain, particularly the bridge of Cordova, over the Guadalquiver. When the arts began to revive in Europe, they were chiefly directed to religious structures. There was little security for travellers, especially in passing rivers, where they were exposed to violent exactions by banditti and robber knights. To put a stop to these disorders, sundry persons formed themselves into fraternities, which became a religious order, under the title of the *Brethren of the Bridge*. The object of this institution was to build bridges, establish ferry-boats, and receive travellers into hospitals on the shores of rivers. The first establishment was upon the Durance, at a dangerous spot named *Maupas;* but, in consequence of the accommodation arising from this establishment, it acquired the name of *Bonpas*. It is related that St. Benezet, who proposed and directed the building of the bridge of Avignon, was a shepherd; and that, at the age of twelve, he was supernaturally commanded to quit his flock, and undertake this enterprise; that he arrived at Avignon at the time when the bishop was preaching to fortify the minds of the people against an eclipse of the sun, which was to happen the same day. Benezet raised his voice in the church, and said that he was come to build a bridge. His proposal was accepted by the people with applause, but rejected by the magistrates and some others. As it was at that time an act of piety to build a bridge, and Avignon was then a popular republic, the people prevailed; and every one contributed to the good work, some by money, and some by labour, all under the direction of Benezet, aided by the Brethren. Upon the third pier was erected a chapel to St. Nicholas, protector of those who navigate rivers. This was done in 1184, after the death of Benezet, who established a conventual house and a hospital, leaving the Brethren to continue the work of the bridge. This bridge was commenced in 1176, and completed in 1188. It was composed of 18 arches. In 1385, during the contentions of the popes, some of its arches were destroyed: three others fell in 1602, from the neglect of repairing a fallen arch. In 1670, the frost was so great that the Rhone, for several weeks, bore the heaviest carriages: when the thaw followed, the piers were destroyed, except the third, which bore the chapel. The fine bridges of Lyons, of 20 arches, and St. Esprit, of 19, were erected by the surviving Brethren of the Bridge.

According to Perronet, an arch of 150 French feet (equal to 160 English feet) span was erected at Verona, in 1354; and, in 1454, one of 183.8 English feet span, and 70.6 feet of rise from the springing, at Vielle Brionde, upon the river Allier, in France. There are also many fine bridges in Italy. The finest in Venice is the Rialto, of 98½ feet span, and 23 feet rise: it was designed by Michael Angelo, and erected between 1588 and 1591. There are no fewer than 339 bridges in Venice.

Some very beautiful bridges have been erected in France during the last two centuries. Plans and descriptions of some of those erected between 1750 and 1772 are given by Perronet. Many of them are of great simplicity and elegance. The bridge erected over the Seine at Neuilly by Perronet is said to be his finest work. It consists of 5 arches, each 128.2 feet (English) span, and 32 feet rise. The breadth, including the parapets, is 48 feet. It was commenced in April, 1768, and opened in October, 1773; the masonry was completed in 1774; the roads, and other operations connected with it were finished in 1780.

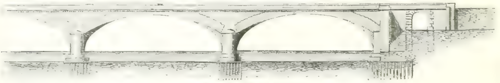

Fig. 266. PONT DE NEUILLY.

The art of bridge-building in England kept pace with its progress on the continent. The singular bridge at Croyland, in Lincolnshire, (Fig. 267) is said to have been built in 860. It has three distinct arches, formed by three segments of a circle, which, meeting in the middle, form pointed arches, their bases or abutments standing upon the points of an equilateral triangle.

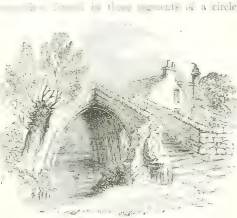

Fig. 267. CROYLAND BRIDGE

Old London Bridge was commenced in the reign of Henry II., under the direction of Peter of Colchester, in 1176, the same year that the bridge of Avignon was begun. The French bridge was completed in twelve years: the erection of the English bridge occupied eighty-three; but this arose from the interruptions which must be experienced in a river where the tide rises twice every day, from 13 to 18 feet. The piles were principally of elm, and remained for six centuries without material decay, although a portion of the bridge fell, and was rebuilt, about one hundred years after it was begun. The stone bridge at Newcastle-upon-Tyne (built in 1281), and that over the Medway, at Rochester, consisting of 11 arches, were erected about the same time as the bridges of St. Esprit and Lyons, already noticed. During several centuries there were houses along each side of London Bridge; but these were removed in 1758. The middle pier was also taken away. The piles were drawn by a very powerful screw, commonly used for lifting the wheels of the water-works; and the space including the two adjacent arches converted into one arch, of 72 feet span. The remaining old arches were very narrow, and the piers of vast size, being from 15 to 25 feet in thickness above the sterlings. Many of the old English bridges were fortified with gateways. In 1636, Inigo Jones designed a bridge, which was erected at Llanwst, in Denbighshire, consisting of 3 arches, segments of circles: the middle one is 58 feet span, and rises 17 feet; the piers are 10 feet thick, and the breadth of the soffit of the middle arch is 14 feet. The arch-stones of the largest arch are only 18 inches deep; the covering over them is small, and the approaches are very steep, so that the bridge has a very light appearance.

In 1738, the situation of the present decayed structure, Westminster Bridge, was agreed on, and Mr. Labalye, the architect, was allowed, after much doubt and difficulty on the part of the commissioners appointed by Parliament, to lay the foundations of the piers in caissons, or chests, filled with masonry, of a form and size suitable to the piers intended to be erected, and floated to the sites of the piers, where they were sunk, the bed of the river having been previously levelled by dredging. This method was adopted instead of placing the foundations upon piles, in the ancient manner, cut off above the level of low water, or using batterdeaux or cofferdams formed around the foundations, and pumping the water from the inside, as had been done in more modern times. The bridge was surmounted by a lofty parapet, the object of which was to secure a sufficient weight of masonry to keep the caissons in place. Labalye states that this bridge contained twice the number of cubic feet of stone used in St. Paul's Cathedral. The bridge was finished in 1747, and was about to be opened, when the following accident happened:—Some workmen employed to get gravel out of the bed of the river, to cover the roadway of the bridge, finding some very suitable near the third pier on the western side of the centre arch, excavated considerably lower than the foundation, and too near it; consequently, the gravel escaped from under the platform, and the pier sunk so much as to make it necessary to take down the two arches which rested upon it. The opening of the bridge was therefore delayed until the 18th November, 1750. This bridge consists of 13 large and 2 small arches: their forms are semicircular; the middle one is 76 feet span, and the breadth over the parapets 44 feet. The system of building on caissons, as illustrated by the subsequent history of this bridge, has proved a failure, and has not been adopted in England. After the removal of old London Bridge, the bed of the river, on which the caissons rest, became undermined so much by the body of water, and increased velocity of the tide, that some of the piers gave way in 1846, so that in August of that year it was found necessary to close the bridge. Portions of the heavy masonry about it were removed, and the bridge itself was considerably lowered. It has remained for some years standing, as it were, upon crutches, awaiting its dissolution. Mr. Page has now (1861) nearly finished a new structure, which will be described in the Appendix.

Blackfriars Bridge was commenced from a design by Robert Mylne, about ten years after the completion of Westminster Bridge. It consists of 9 elliptical arches. The middle arch is 100 feet span; the length of the bridge is 995 feet from wharf to wharf; the breadth across the bridge is 43 feet 6 inches. The piers were built in caissons; but piles were previously driven for the caissons to rest upon. The arches being of wider span and of an elliptical form, and the piers of proportionally less thickness, and having less masonry over the top of the arches, this bridge has a much lighter appearance than that of Westminster. The expense of Blackfriars Bridge, including the purchase of premises, was about 260,000*l.*: that of the building was only 170,000*l.* Westminster Bridge cost about 400,000*l.* Blackfriars Bridge was made passable as a bridle-way on the 19th November, 1768, and was generally opened on the 19th November, 1769. There was a toll of one halfpenny for every foot passenger, and one penny on Sundays, until the 22d June, 1785, when Government bought the toll, and made the bridge free. A few years ago, the bridge was lowered, and the open balustrade removed.

It is impossible in this brief sketch to notice the various bridges erected in modern times in Great Britain and Ireland. Some of them will be incidentally noticed in the different sections of this article. We cannot, however, refrain from giving a few details respecting the beautiful bridge which has taken the place of old London Bridge.

The old method of laying the foundations of piers, which was introduced soon after the Conquest, was very defective, and was particularly exemplified in the old London Bridge. "The masonry commenced above low-water mark, being supported on piles, which would have been exposed to the destructive alternation of moisture and dryness, with the access of air, if they had not been defended by other piles, forming projections, partly filled with stone, and denominated *sterlings*, which, in their turn, occasionally required the support and defence of new piles surrounding them, since they were not easily removed when they decayed; so that, by degrees, a great interruption was occasioned by the breadth of the piers, thus augmented, requiring, for the transmission of the water, an increase of velocity, which was not only inconvenient to the navigation, but also carried away the bed of the river under the arches and immediately below the bridge, making deep pools or excavations, which required from time to time to be filled up with rubble-stones; while the materials which had been carried away by the stream were deposited a little lower down, in shoals, and very much interfered with the navigation of the river." From these circumstances, as well as from the effects of time and decay, it happened that the repairs of the old London Bridge often amounted, for many years together, to 4,000*l.* a-year. "It is true that the fall produced the trifling advantage of enabling the London water-works to employ more of the force of the tide in raising water for the use of the city; and this right being established as a legal privilege, long delayed the improvements which might otherwise have been attempted for the benefit of the navigation of the river. The interest of the proprietors of the water-works had been valued at 125,000*l.*, and it had been estimated that 50,000*l.* would be required for the erection of steam-engines to supply their place; while, on the other hand, from thirty to forty persons, on an average, perished annually, from the dangers of the fall under the bridge."

The consequence of removing the centre pier was somewhat to diminish the fall; but it was found necessary to obstruct the channel again, in order that the stream might have force enough for the water-works. But it was very difficult to secure the bottom from the effects of the increased velocity under the arch. A number of strong beams were fixed firmly across the bed of the river; but only two of them remained for any length of time, and the materials carried away were deposited below the middle arch, so as to form a shoal which was only sixteen inches below the surface at low water.

At length, after the bridge had been for more than six hundred years exposed to the constant action of a rapid current, it was determined to erect a new bridge. The loss of life and property was frequent, in consequence of the great velocity with which barges and smaller craft were carried by the stream through its arches, and of their descent, by means of a considerable fall, from one level to another. In 1823, an Act was obtained for rebuilding the bridge, and for making suitable approaches to it. John Rennie was appointed architect; but, as he died before the bridge was begun, the execution of his plan was confided to his son, Sir John Rennie. The new bridge, consisting of five elliptical arches, was intended to be on the site of the old one, and to correspond with the old approaches. It was, however, afterwards determined to construct it 180 feet higher up the river, so as to avoid the steep ascent of Fish Street-hill. The first pile of a cofferdam for the south pier was driven on the 15th March, 1824, and the first cofferdam was completed on the 27th April,

1825. It consisted of three rows of piles, dressed in the joints, and shod with iron; and many of them were 80 or 90 feet long. The first stone of the bridge was laid on the 15th June. The foundations of the piers are of wood, piles of beech being first driven in the interior of the dam, to a depth of nearly 20 feet, in the stiff blue clay which forms the natural bed of the river; two rows of horizontal sleepers, about 12 inches square, were then laid on the head of these piles, and covered with beech planking, 6 inches thick, on which the lowermost course of masonry was laid.

The obstruction caused by the works of the new bridge rendered it necessary to throw two of the small arches of the old bridge at each end into one, which was done in about six weeks.

The centerings for supporting the arches of the new bridge were required to be of great strength, because the flatness of an elliptical arch produces a greater load on the centering, while building, than the semicircular arch does. Each centre consisted of ten frames, or ribs, supported at the two ends on piles driven into the bed of the river. These frames were boarded over on the top with stout planks. The arches, being unequally wide, required four sets of centres, each containing nearly 800 tons of timber. The first arch was keyed in on the 4th August 1827, and the last on the 10th November, 1828. Instead of filling up the spandrels of the arches with loose rubble-work, according to the usual practice, longitudinal or hance walls were built over the arches, and over these large blocks of stone were bedded, surmounted by heavy stone landings, on which is a course of cement, and over that the roadway. The approach from the city side is brought to the level of the bridge by a series of land arches in continuation of the bridge. The bridge was completed on the 31st July, 1831. It consists of five elliptical arches: the centre arch is 152 feet span, with a rise of 29½ feet above high-water mark. The two arches next the centre are 140 feet span, with a rise of 27½ feet; and the two abutment arches are 130 feet span, with a rise of 24½ feet. The piers are solid, and rectangular in form. The great diminution in masonry work, in consequence of the form of the arches, allowed the piers to be greatly diminished in size. The line of roadway is a segment of a very large circle, the rise being only 1 in 132. The abutments are each 73 feet wide at the base, and spread out backward, so as to sustain the thrust of the bridge with best effect. The length of the bridge, from the extremities of the abutments, is 982 feet, and, within the abutments, 728 feet. The roadway is 53 feet between the parapets, being 8 feet wider than the old bridge, and 11 feet wider than any other bridge on the Thames. The foot-ways occupy 9 feet each, and the carriage-way 35 feet. The bridge is of the finest granite, from the quarries of Aberdeen, Heytor, and Penryn. The total quantity of stone was about 120,000 tons.

SECTION II.—THEORY OF STONE BRIDGES.

The theoretical principles of stone bridges contain the mathematical demonstrations of the properties of arches, the thickness of the piers, the force of the water against them, and other abstruse but necessary calculations. This branch of the subject, which has exercised the talents and ingenuity of some of the greatest mathematicians in modern times, is not sufficiently elementary for the present work; but it may be interesting to give a short abstract of Professor Moseley's theory of the arch, chiefly abridged from Mr. Weale's beautiful work, already referred to, with occasional reference to the accomplished Professor's popular works, entitled, "Illustrations of Mechanics," third edition, London, 1846, and "Mechanics applied to the Arts," third edition, London, 1847. We will, however, first describe the various parts of an arch.

An arch may be defined as a collection of wedge-formed bodies, named *voussoirs*, or *arch-stones*, *v v*, Fig. 268, the first and last of which are sustained by a support or abutment, A B, while the intermediate ones are sustained in their positions by their mutual pressures, and by the adhesion of the cement interposed between their surfaces. The centre voussoir, *k*, or that in the highest part or *crown*, C, of the arch, is called the *key-stone*. The inferior surface of the arch, *s f h f s*, is called its *intrados*, and sometimes its *soffit*; but this latter term is also occasionally restricted to the under surface of the arch, *h*, at its key-stone or crown. *s f f s* are the *flanks* of the arch. The exterior surface, *e C d*, is called its *extrados*, or *back*. The points *s s*, where the intrados meets the abutment, are called the *springings*, their horizontal direction, *s i s*, the *span*, and the distance *i k* the *rise* or *height* of the arch.

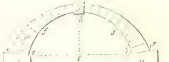

Fig. 268.

Such a structure, or, indeed, any structure, built up with uncemented stones, may fall, either by the opening of some of the joints, causing the stones to *turn* on the edges of one another after the manner of a hinge, or by the stones slipping upon one another.

These two cases are represented in the following figures. In Fig. 269, an arch is falling by the turning of its voussoirs at the crown upon the upper edges of one another, and, at the haunches, upon their lower edges. In Fig. 270, the arch falls by the sliding of the arch-stones near the abutment downwards, and by the sliding of those near the crown upwards. The latter case is, however, of rare occurrence; for such is the friction of the surfaces of the stones used in construction, that their slipping upon one another is probably unknown in practice; yet, until within the last few years, the slipping of the voussoirs upon one

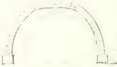

Fig. 269.

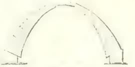

Fig. 270.

another was considered to involve the whole question of the stability of the arch.

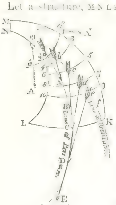

Fig. 271

Let a structure, M N L K, Fig. 271, composed of a single row of uncemented stones, of any forms, and placed under any given circumstances of pressure, be intersected by a surface 1, 2, and let the resultant a A of all the forces which act upon one of the parts, M N 2 1, be taken. Then let this intersecting surface change its form and position, so as to coincide in succession with all the common surfaces of contact, 3 4, 5 6, 7 8, 9 10, of the stones which compose the structure, and let b B, c C, d D, e E, be the resultants, similarly taken with a A, which correspond to those several planes of intersection. In each such position of the intersecting surface, the resultant spoken of, having its direction produced, will intersect that surface either *within* the mass of the structure, or, when that surface is produced, *without* it. If it intersect it *without* the mass of the structure, then the *whole* pressure upon one of the parts, acting in the direction of this resultant, will cause that part to turn over upon the edge of its common surface of contact with the other part; if it intersect it *within* the mass of the structure, it will not. Thus, if the direction of the resultant of the forces acting upon the part M N 1 2 had been a' A', not intersecting the surface of contact 1 2 *within* the mass of the structure, but supposed to be produced beyond it into a'; then the whole pressure upon this part acting in a'A would have caused it to turn upon the edge 2 of the surface of contact 1 2. So, also, if the resultant had been in a'' A'', then it would have caused the mass to revolve upon the edge 1. But the resultant having the direction a A, the mass will not be made to revolve on either edge of the surface of contact 1 2.

Thus, the condition that no two parts of the mass should be made by the insistent pressures to turn over upon their common surfaces of contact, is involved in this other, that the direction of the resultant, taken in respect to every position of the intersecting surface, shall intersect that surface actually within the mass of the structure.

If the intersecting surface be imagined to take up an infinite number of other positions, 1 2, 3 4, 5 6, &c., and the intersections with it, a b c d, &c. of the directions of all the corresponding resultants be found, the curve line a b c d e f, joining these points of intersection, is named by Professor Moseley the *line of resistance*. This line can be completely determined by the methods of analysis, in respect to a structure of any given geometrical form, having its parts in contact by surfaces also of given geometrical forms. And conversely, the form of this line being assumed, and the direction which it shall have through any proposed structure, the geometrical form of that structure may be determined, subject to these conditions. Or lastly, certain conditions being assumed, both as it regards the form of the structure and its line of resistance, all that is necessary to the existence of these assumed conditions may be found. Let the structure A B C D, Fig. 272, have for its line of resistance the line P Q. Now, it is evident that if this line cut the surface M N of any section of the mass in a point n, without the surface of the mass, then the resultant of the pressures upon the mass C M N will cut through n, and cause this portion of the mass to revolve about the nearest point N of the intersection of the surface of section M N with the surface of the structure.

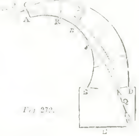

Fig. 272.

It is therefore a condition of the equilibrium, that the line of resistance shall intersect the common surface of contact of each two contiguous portions of the structure actually within the mass of the structure; or, in other words, that it shall actually go through each joint of the structure, avoiding none: this condition being necessary, that no two portions of the structure may revolve on the edges of their common surface of contact.

Let us borrow from the same competent authority another illustration of this great condition of the equilibrium of an edifice. Let the extreme stone, Fig. 273, of an edifice of uncemented stones have impressed upon it any given force, P. In addition to this force, the stone is acted upon by gravity, which may be supposed to be collected in its centre of gravity. The resultant of these two forces will represent the whole force by which the first stone is pressed upon the second. If this resultant have its direction anywhere within the edges of the joint or surface of contact of the first stone with the second, the one will rest upon the other; if not, it will turn over upon it. The second stone may be considered to have its upper surface acted upon by the resultant force just spoken of, and this to be the only force pressing it downwards, besides its own weight, collected in its centre of gravity. If, then, a second resultant be taken, being that of two forces, of which the first resultant is one, and the weight of the second stone the other, then this second resultant will be that force by which the second stone may be supposed to be pressed upon the third. If its direction lie within the edges of the joint of the second and third stones, the second will rest upon the third; if not, the superstructure will turn upon the third stone. So, also, if a third resultant be taken, being that of two forces, of which one is the second resultant, and

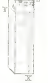

Fig. 273.

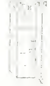

Fig. 274.

the other the weight of the third stone, then this third resultant will be that force by which the third stone is pressed upon the fourth; and the conditions of the equilibrium of this third stone are, that this resultant shall have its direction within the edges of the joint of the third and fourth stones: and so on of the rest. If we now suppose that the intersections of all these resultants with the planes of the joints of the successive stones are found, by mathematical investigation, and a line be drawn through all these points of intersection, we get the line of resistance before spoken of. If this line, which is a curve, have its direction anywhere beyond the joints of the stones, the edifice will be overthrown at such joints; but if the curve nowhere lie without the mass of the edifice, it will nowhere be overthrown by the turning of its joints.

But there is a second condition necessary to the stability of the structure. Its surfaces of contact must nowhere slip upon one another. That this condition may be satisfied, the resultant corresponding to each surface of contact must have its direction within certain limits. In Fig. 271, the line A B C D E, formed at the points of the consecutive intersections of the resultants *a* A, *b* B, *c* C, *d* D, &c., is termed the *line of pressure*. Its geometrical form may be determined under the same circumstances as that of the line of resistance. A straight line, *c* C, drawn from the point *c*, where the line of resistance *a b c d* intersects any joint 5 6 of the structure, so as to touch the line of pressure A B C D, will determine the direction of the resultant pressure upon that joint: if it be within a cone defined by Professor Moseley as a right cone, having the normal to the common surface of contact at the point of intersection of the resultant for its axis, and having for its vertical angle twice that whose tangent is the coefficient of friction of the surfaces, the structure will not slip upon that joint; if it lie without it, it will.

Thus, the whole theory of the equilibrium of any structure is involved in the determination, with respect to the structure of these two lines,—the line of resistance, and the line of pressure: the former determining the point of application of the resultant of the pressures upon each of the surfaces of contact of the system; the latter, the direction of that resultant.

In an upright pier or wall, the line of resistance is a hyperbola, the position and magnitude of which may be determined by construction. Resolve the force P, Fig. 273, which presses upon the summit of the pier, into two others, one of which is in a vertical and the other in a horizontal direction. Calculate the height of a mass which, being of the same substance and thickness as the pier, shall have a weight equal to the vertical force of these two, and let this height be A T. Calculate in like manner the height of a mass whose weight shall equal the horizontal force, and let this height be A S. [illegible] line, Fig. 274, [illegible] Take E G, [illegible] of the width of the pier, and se[illegible] [illegible] draw the vertical G C. C will be the centre of the hyperbola, and the vertical C E X will be its asymptote. Now, the curve of a hyperbola always approaches, but never touches, its asymptote. The curve of resistance always, then, approaches, but never touches, the line C X; and if this line lie, as in the figure, within the mass of the sphere, then the line of resistance, never passing the line C X, can never cut the outward surface of the pier; and, however tall it may be, the pier can never be overthrown by the action of this force. It is also a remarkable feature of the theory, that the pier will bear this insistent pressure P wherever in A G it is applied parallel to its present direction; the position of the centre of the hyperbola, C, not being changed by any alteration in the point of application of that pressure, but only in its magnitude.

Professor Moseley also gives the following method for determining the greatest height to which a pier can be built, so as to sustain a given pressure upon its summit. If A E, Fig. 273, be greater than half the width of the pier, or if G lie beyond B, then there will be some point in the outward surface or extrados of the pier where the line of resistance will cut it; and there will therefore be a certain height beyond which the pier cannot be carried without being overthrown. This height is thus determined. Let P, Fig. 274, be the point where the insistent pressure intersects the summit of the pier, and let A S, and A T, and E G be taken as before; join U G, and through P draw P Z, parallel to U G. Z will be the point where the line of resistance cuts the extrados, and will indicate the greatest height to which the pier can be carried without being overthrown; or, if it can be carried higher, then is this the point to which an inclined buttress should be built to support it.

The details which have been given will enable the reader to form a general idea of the application of the theory of the line of resistance to the conditions of the equilibrium of the arch. It is a general condition that this line, R Q A Q' R, Fig. 275, (which represents an arch having the joints of its voussoirs perpendicular to the intrados, as they are usually made) touches the intrados or inner surface of the arch on both sides at its haunches, Q Q', and the extrados at the crown, in A, and that afterwards, at lower points, it cuts the extrados or outer surface of the arch at R R'. If some resistance, of an abutment or pier, be not opposed at this last point to the pressure, the whole of which acts there, the arch will be overthrown. If it be supported there by a pier, the line of resistance passes into the pier, and assumes a new character and direction; that direction having a general tendency towards the back or outer surface of the pier. If, by reason of the comparatively small height of the pier, the line of resistance does not anywhere reach the back of the pier, but intersects its base, the pier will stand. But if the height be

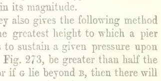

Fig. 275.

so great as to cause the line of resistance to cut the back of the pier at some point above its base, then the pier will be overthrown, and the arch will fall. When the arch falls, the line of resistance is made to cut the intrados at the points in the haunches, Q Q', where before it touched it. Hence, these points are called the *points of rupture*. The line of resistance thus cutting the intrados of the arch at these points, the direction of the whole pressure is made, at these points, to act beyond the joints of the stones there, so that it causes the stones to turn upon their lower edges, and to open at their upper edges. Besides touching the intrados at the haunches, it is another general characteristic of the line of resistance, in the state of the equilibrium of the arch, that it touches the extrados over the crown, at A, and that when the arch is falling, it is made to cut the extrados there: so that the pressure, there also, acting beyond the joints of the stones, causes them to turn, but, in this case, on their superior, instead of their inferior, edges. The arch then opens at the crown, A, at its intrados, and thus it falls, separating itself into four distinct parts as in Fig. 276. This is precisely what has been observed to be the process of the fall of the arch in experiments made for the purpose. M. Gauthey having occasion to destroy a bridge, caused one of its arches to be isolated from the rest; and the adhesion of the cement being sufficient to counteract the tendency of the pressure to rupture the piers, he caused them to be cut across. The whole then at once fell, the falling portion separating itself into four parts. Having constructed small arches of soft stone, and without cement, he loaded them until they fell. Their fall was always observed to be attended with the same circumstances. Before the arch finally yielded, the stone was observed to chip at the intrados, about the points Q Q', round which the upper portions of it finally revolved.

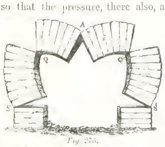

Fig. 275.

Professor Robison also relates some similar circumstances connected with the failure of a considerable arch. It had been built of an exceedingly soft and friable stone, and the arch-stones were too short. About a fortnight before it fell, chips were observed to be dropping off from the joints of the arch-stones, about ten feet on each side of the middle, and also from another place on one side of the arch, about twenty feet from its middle. The masons in the neighbourhood prognosticated its speedy downfall, and said it would separate in those places where the chips were breaking off. At length it fell; but it first split in the middle, and about fifteen or sixteen feet on each side, and also at the very springing of the arch. Immediately before the fall, a shivering or crackling noise was heard, and a great many chips dropped down from the middle, between the two places from whence they had dropped a fortnight before. The joints opened above at those new places more than two inches, and in the middle of the arch the joints opened below, and in about five minutes after this, the whole came down. Even this movement was plainly distinguishable into two parts. The crown sunk a little, and the haunches rose very sensibly, and in this state it hung for about half a minute. The arch-stones of the crown were hanging by their upper corners; when these splintered off, the whole fell down.

Professor Robison caused models of arches to be made in chalk, and loaded them at the crown until the line of pressure cut the extrados, and they fell. The material of the arch would of course be most likely to yield at those points where the line of resistance most nearly approaches the intrados; and in these experiments the chalk was observed to chip and fall off there before the final rupture. Having loaded his arches at the crown until they fell, he observed, however, that the points where the material began to yield were not precisely those where the rupture finally took place. This would necessarily be the case; for any variation in the least force which would support the semi-arch, if applied at its crown, would cause a corresponding change in the position of the points Q and Q', Fig. 275. Now, as the load on the crown is increased, this force is also increased, and the result is a variation in the form of the line of pressure, tending to carry its point of contact with the intrados lower down upon the arch. Accordingly, it was observed that the arch began to chip at a point about half-way between the crown and the point where the rupture finally took place.

It will be seen by a reference to Fig. 275, that above the points Q and Q' the direction of the line of resistance is such as to indicate a direction of the pressure which would produce in the arch-stones a tendency to slide downwards upon one another, while below that point the tendency is to slide upwards. Hence, it might be expected that when the *centre*, or wooden frame, used for supporting the arch-stones during the erection, was removed, the motion of the arch-stones[1] would be slightly downwards, in reference to those voussoirs which are above the points Q and Q, and upwards in reference to those which are below those points. This motion of the voussoirs among themselves, on the removal of the centre, produces what is called the *settlement* of the arch, and this settlement is observed to take place precisely under the circumstances above described. At the bridge of Nogent-sur-Seine, before removing the centre of the arch, Perronet caused three lines to be cut upon the face of it, (Fig. 277) one horizontally, immediately above the crown, and the other two lying obliquely from the extremities of this on either side, towards the springing of the arch. After the striking of the centre, these lines were observed greatly to have altered their forms, and even their relative positions on the face of the arch. All of them had, from straight lines, become curves. The horizontal line had sunk throughout its whole length, its greatest deflexion being

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[1] The arch-stones would admit of some degree of motion among one another, by the yielding of the cement, or by reason of the closer degree of contact into which the additional pressure would bring them.

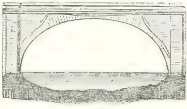

Fig. 277.

immediately above the key; thus indicating a downward motion in all the voussoirs on which this line was traced. The oblique lines, too, had on either side deflected from their first position towards the intrados of the arch, or downwards, up to certain points, corresponding to Q and Q'; beneath these points the deflexion was from the intrados of the arch, or upwards. Thus, among the voussoirs on which the oblique lines were cut, there was shown to be a downward motion, in respect to those above the points corresponding to Q and Q', and an upward motion in respect to those beneath those points. The same phenomena were observed to attend the settlement of other great arches constructed by Perronet, especially those of the Pont de Neuilly.

An arch may be so loaded about its haunches as entirely to alter the direction of its line of resistance; in which case it will be overthrown as effectually as by the too great height or insufficient weight of its piers in respect to the load it bears on its crown. An excessive load on its haunches may entirely alter the line of resistance, so as to flatten it at the top, and give it two elbows on either side of the crown, causing it to cut the intrados instead of the extrados at the crown, and the extrados at two points a short distance on either side of the crown; the points where it touches the intrados being by this process thrown much lower down upon the arch. The arch will in this case fail by the rising of its crown and the falling in of its sides. The great art of arch-building consists in so loading the arch as to secure it against either of these contingencies.

SECTION III.—ON THE PRACTICE OF BRIDGE-BUILDING.

THE practice of bridge-building requires a large amount of knowledge on the part of the engineer or bridge-architect, and has reference to the *situation*, the *design* and the *materials* of the bridge, which of course may vary according to circumstances. The bridge itself has reference to the *foundations*, the *piers and abutments*, the *centres*, the *arches*, the *spandrels and wings*, the *parapets* and the *roadway*, which are also subject to great variation, according to the taste and skill of the architect, and the means at his disposal.

1. *The situation* of a bridge must be determined by local circumstances, as in a town by streets and in the country by the adjacent roads. In laying out a new line of road through a country, choice may often be made of the points for crossing rivers, and as a bridge must always be a very costly portion of the road, it may be expedient to go out of the direct line to places at which crossings may be most conveniently effected. In general, the best point upon a river for a bridge, is where the stream is narrowest, and where the banks are raised sufficiently to form natural approaches, and are solid enough to form natural abutments. There may, however, be exceptions to this. "Where a river is narrowest it is deepest and most rapid, and where the banks are high and consistent enough to form approaches and abutments to a bridge, the water will rise higher in floods than at any point lower down, where it may have more room laterally. Unless, therefore, the crossing can be effected in one span, reach or bay, so as to avoid a pier or piers, it may be less expensive, and more certain to build a longer bridge over a wider part, and to form artificial approaches and abutments, than to construct a sufficient and perfect bridge where nature has provided both approaches and abutments, and where the traject is shorter. It does not often occur moreover, that both banks of a river are high in the same place; and again, where one bank of a river is elevated or cliff-like and of good consistence, it is very likely to have been the means of reflecting or throwing the water off to act upon the opposite bank, and so have itself become the head of a reach, or the concave face of a bend, where the stream is very generally widest. When circumstances admit of a bridge over a river being in one span or reach, or of one bay, it is comparatively unimportant whether it be placed upon a bend of the river or not, if it be so contrived as to give sufficient head-way for craft where the channel is, or, in other words, where the water is deepest, which in a bend is most frequently on the concave side. When piers in the water way are determined to be necessary for an intended bridge, the site should be chosen where the course of the river is straight, so that the bridge may be placed at right angles to the thread of the stream, and that the piers may thereby intercept and divide the water in the least objectionable manner. In a running river, the longest part of a straight reach may be left above the bridge with advantage, whilst in a tidal river the bridge should be placed in such a manner as to give the stream at both ebb and flow all the advantage that can be obtained from the piers lying in the direction of the currents; and where, as it must be in most cases, the down stream is the strongest, and the ebb of longer duration, the proportion of the reach above and below a bridge should be determined accordingly."[1]

2. *The design.* When the situation of a bridge has been determined, a careful survey must be made of it, and a plan be laid down of the channels and adjacent banks, and of the streets and roads to be connected at each end of the bridge. The plan should present an outline or representation upon a horizontal

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(1) Professor Hosking's Essays and Treatises on the Practice and Architecture of Bridges, inserted in Mr. Weale's work, on the Theory and Practice of Bridges.

section of lines raised vertically from every point of the surface of the ground. A plan of the site, as from A to B, Fig. 278, laid down from measurements made along the bending line of the surface,

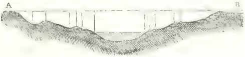

Fig. 278.

would give a much greater length than a plan upon a horizontal section of lines raised vertically from the surface of the ground to the straight horizontal line A B. Such a section must show the irregularities of the ground, the various substances of which the ground is composed, and the thickness vertically of each substance as far as it is necessary to ascertain it; that is, until a proper substance upon which to work has been found. This may be obtained by boring. In addition to the transverse section of the river, which is the direction to give the longitudinal elevation of the proposed bridge and its approaches, a longitudinal section of the river transversely of the bridge must be taken to show the declivity of its bed, and to exhibit any unsound strata that may lie near the proposed site. Upon both sections of the river, the ordinary depth of water in it, the highest level it ever attains, and the lowest to which it falls, should be ascertained and recorded, as also the velocity of the stream and the quantity of water passing down the river at all times and seasons of the year.

3. *The materials* of which bridges are constructed are various, such as *timber*, the art of combining which is known as CARPENTRY; *stone*, the working and setting of which is called MASONRY; *brick*, the composition of which is termed *brick-work; iron*, which is prepared by the founder, and fixed and fitted by the smith, and known as *iron-work*. "Although a bridge may be built almost entirely of timber, as indeed bridges are often built,—except as to the smith's work in the form of shoes, rings, hoops, straps, bolts, nuts, washers, spike and other nails, which the carpenter finds essential to the proper and efficient combination of his principal material;—the best timber bridges are those in which solidity and evenness of pressure, with power of resistance and retention, are given by piers and abutments of masonry or brick-work; and in like manner, what is called an iron-bridge, may be said to require that its piers and abutments, or other points of support, shall be of masonry, or of a combination of mason's work and brick-work. Bridges are built and in some cases most efficiently so, of brick-work alone; but, that a brick-bridge may be durable and sightly, it is almost always necessary, and it is always desirable, that some of the more exposed parts should be of stone. Masonry may stand alone in the composition of a bridge, but neither brick-work nor masonry alone, nor the two in combination, can be made to effect such objects as may be attained by the aid of the iron founder and smith, and indeed, of the carpenter with his timber."

But the chief material of a bridge must be determined by local circumstances, as one place may furnish one kind of material and not others; but timber must nevertheless be most extensively and variously applied, not only as a bridge-building material, but as an auxiliary in the erection of a bridge with other materials. Yet of all the materials used in bridge-building, timber is the most perishable, although modern science has contrived methods of protecting it from many of the causes of decay. Iron as a bridge-building material possesses many valuable properties. Its tenacity and power of resistance in a comparatively small bulk, allow works to be constructed and effects to be produced, which belong to no other available material. It is however greatly affected by change of temperature, and is hence unstable in framing. It is also injurious to the material which it thrusts against or is connected with, and it wastes away by oxidation and other chemical processes. As an auxiliary in bridge-building iron is second only to timber, and both iron and timber are necessary in bridge-building, although neither may enter into the composition of a structure. Stone, however, is pre-eminently the material for bridges, whether we regard its grandeur of effect, its power of resistance and endurance, its unyielding nature, its massiveness, its capability of being cut or wrought to any form, size or figure, and its retentiveness of the form given to it; it has scarcely any tendency to change in bulk from changes in temperature, and it is inaccessible to moisture. Its practical want of elasticity prevents it being disturbed by concussions, but being readily frangible, it can only be used and applied where it shall not be subjected to transverse strains. Hence it is unfit for beams or for bearing across over a void, and for situations where it is liable to disturbance from concussions. The inelasticity and frangibility of stone prevent a combination of parts by framing, as is done with timber and iron; but if the stone be cut up into pieces of certain forms previously arranged, as in the arch, it will carry a much greater weight than if thrown across the same space in the form of a beam or lintel; but the parts so arranged require the restraint of an extraneous tie, or a loading of the abutments and haunches not necessary to the level bearing across, and which a susceptibility of being framed would have obviated.

Brick must be regarded only as a substitute for stone, where stone cannot be obtained. Brick resembles stone in being practically incompressible and inflexible, but being prepared in small, regular and equal forms, it must be combined with cement or mortar, which, from its nature and mode of preparation, is yielding and liable to change until it has set and become perfectly dry. An arch turned with uncut bricks depends entirely on the mortar with which the bricks are packed, and is hence liable to change its form and become insecure while the mortar remains incompressible or less hard and unyielding than the substance of the brick. It is, however, not uncommon to strike the centering of brick arches before the mortar is properly set, in order, as is supposed, to allow the materials to settle and consolidate by mutual pressure. This practice has probably led to the destruction of many of the large brick arches recently constructed on some lines of railway. A combination of brick and stone produces excellent results in bridges, the stone being introduced in chains and strings to assist in binding the brick-work, and in springing, blocking and coping courses and upon salient and exposed parts generally, and to receive and distribute pressure where it is greatest.

It may be stated as a general rule, that wherever the object to be attained in the use of a bridge can be effected by timber, the same end may be answered better and more effectually, both for use and durability with iron; and where the object proposed in the use of a bridge can be attained by the use of brick, the same thing can be done more effectually with stone; while iron and stone can often be applied where timber or brick could not be used. Probably in all cases where there is a choice between iron and stone, the latter will deserve the preference; but the art of constructing a bridge in the readiest, cheapest and simplest form will greatly depend on the facility of procuring materials. Bridges, like roads, canals and other means of transit, are often necessary to give value to the products of industry, and must be adapted in many cases, as in that of an infant community, a new colony, for example, to supply the want with the smallest expenditure of labour.

We come now to notice the practice of bridge building chiefly with reference to stone bridges, taking the several parts of the bridge in the order enumerated at the head of this section.

1. *The foundations* of a bridge consist of the underground work of the piers and abutments, and these require to be constructed with the utmost care in order to produce firm and solid bases whereon to carry up to any required height the various pedestals of support for the arches of the bridge. Alberti's distinction between the structure above-ground and the foundations of any building is applicable to bridges. He considered the foundation, not as a part of the structure itself, but as an artificial support on which the latter is to be placed; and remarks, that if the natural site of a building consisted of rock or other stratum equally hard with the material of which foundations are constructed, these would be unnecessary, and the building might be commenced and carried up without previous preparation of the bottom. Gauthey also remarks that the solidity of a bridge depends almost entirely on the manner in which its foundations are laid. When these are once properly arranged, the upper part may be erected either with simplicity or elegance, without impairing in any degree the durability of the structure. Experience has proved that many bridges either decay or are swept away by sudden floods, by reason of the defective mode of fixing their foundations, while very few suffer from an unskilful construction of the piers and arches.

In constructing the foundation of bridges which are to pass over roads or railways, the absence of water removes the greater part of the difficulty which is met with in spanning a wide and rapid stream; for if the bottom be unsound, the stability of the work may be ensured by driving piles, or by using concrete. In crossing narrow streams, the abutments may often be founded on dry land, or the course of the river may be turned and the piers constructed in the dry bed; but where none of these facilities are afforded, the bridge architect or engineer will have to contend against all the difficulties of operating in the midst of water.

In the ancient practice of bridge building, two methods were adopted for constructing the foundations. For shallow rivers stones were sunk to the bottom in strong baskets made of the pliable boughs or branches of trees; when this rude basket or caisson was sunk, stones were added until they were piled up to within a foot or 16 inches of the lowest water surface. In later times this plan was improved upon by forming wooden chests strongly hooped with iron, and constructing in them above-ground masses of masonry, which were sunk into the bed of the river. This method was practised by Labelye in the construction of Westminster, and by Mylne in the construction of Blackfriars bridges.

According to the second ancient method where strong currents existed, and it was necessary to construct the piers on dry ground, the plan adopted was to form the piers at some convenient distance from the river, in a range with the general direction of the stream, and at right angles with some good and direct approach previously selected, leading to and over the bridge, and when the bridge was completed to turn the course of the river by a new channel through the water way of the bridge. In Fig. 279 we have the plan of a bridge to be built in a neck of land formed by a bend of the river, which must afterwards be diverted from its course in the direction of the dotted line A B, and the roadway can be readily embanked across the old channel, which will be laid dry. Even where the course of the river is nearly straight, the difficulties and expense of constructing the piers in the water may be so great as to warrant the engineer in slightly turning the river as in Fig. 280. which shows the appearance of the diversion, the bridge having been built on dry land on one side of the old channel, thus affording the advan-

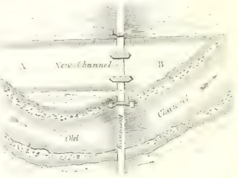

Fig. 279.

tage of a firm bottom at very moderate cost, compared with the other situation.

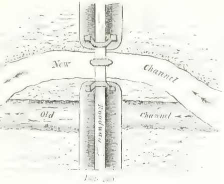

Fig. 250.

In the old bridges, if the bottom proved unsound, piles, 3 or 4 feet apart, were driven down over the site of the proposed piers; and instead of cutting off the pile heads evenly, and planking them over with timber, as is now done, it was customary to fill in between them with a species of coarse concrete,[1] which being brought to a level surface, formed the bed on which the first course of stone was placed. Another ancient method of using piles for building in water, and still used by the French, who call it *encaissement*, consisted in driving in main piles with sheet piling between them, secured and bound round with waling as in the modern coffer-dam, but only one row of piles was driven all round the space of the pier or abutment to be founded, and not a double row of piles to be filled with clay, as in a coffer-dam. The encaissement being formed, and the loose soil, &c. got out, a mass of concrete or dry rubble stones is thrown in until a sufficient foundation is formed reaching to the level of the water. After being allowed some time to settle, the dressed masonry is laid in courses upon the foundations thus formed. A design by Mr. Semple will illustrate this mode. In a river 6 feet deep he proposed to drive sheeting piles about 10 feet in length, to a depth of 4 feet in the ground all round the site of each pier, and to fill the space or coffer thus formed with a bed of concrete 6 feet in depth. The top of the concrete being level with the surface of summer low-water mark, the masonry was to be commenced therefrom and carried up to springing height clear of the water.

Mr. Hughes remarks that "on examining the foundations of old bridges, particularly in this country, they are all found to be extremely massive, and the piers were even carried up above water of a thickness quite incommensurate with the necessity of the case. On inspecting the masonry of their foundations, however, it is found that no very great attention has been paid to the regularity of courses, or to the perfection of beds and joints. Some of the strongest specimens of ancient masonry existing in this country, consist of a kind of building little superior to rubble walling, with this most important qualification, that the mortar is always of an excellent description, and in most cases by no means inferior in hardness and cohesiveness to the stone itself."[2] The mortar usually contained a great number of small stones or pebbles, some of them equal in size to a pigeon's egg, and was altogether much coarser than that used at the present day. Another point of difference between ancient and modern bridges is, that in modern times engineers form their bridges with as few arches as possible; the ancient structures "consisted of a long low series of culverts, hardly deserving the name of arches, with intervening piers often of greater thickness than the span of the arches they were built to support." The weight of such a bridge distributed over a great many points, such as the 20 or 30 piers sometimes built in the old bridges, each pier had scarcely more to support than its own weight. "The ancients in their bridges throughout the whole structure, substituted quantity for quality, that is to say, large masses of rough undressed masonry, or rubble, instead of the firm, compact and elegant piers of modern bridges, which, above the bed of the river at all events, are invariably built with the most durable stone, of well-squared dressed ashiar fronts, and suitable filling within." In some cases, however, there is no objection to these coarse and massive subaqueous structures, and provided they do not obstruct the free course of the river, they may be of great advantage, especially in projecting sea piers and similar structures.

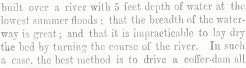

Fig. 251. THE BRIDGE OF FABRICIUS AT ROME.

In modern times, the invention of the coffer-dam has enabled the engineer to secure a firm foundation in the bed of the river. Suppose a bridge is to be built over a river with 5 feet depth of water at the lowest summer floods; that the breadth of the waterway is great; and that it is impracticable to lay dry the bed by turning the course of the river. In such a case, the best method is to drive a coffer-dam all round the space which is to be occupied by the piers and abutments. The depth of water being 5 feet, suppose that of the unsound bottom to be 25 feet: the piles must not be less than 45 feet long, and must be driven into the solid ground as far as they will go, which may be from 8 to 10 feet. For such a depth of water, a double dam, with three rows of piles, will be required. The coffers between the rows of piles should be 6 or 7 feet apart, and filled with a retentive

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(1) Called by the French *béton*. It seems now to be generally admitted, that the use of a concrete mixture composed of lime and coarse gravel, was common among the Romans. The use of concrete in modern times on a large scale, was introduced by Mr. Peter Semple, architect of a bridge over the Liffey at Dublin.

(2) A series of papers on the Foundations of Bridges. By T. Hughes, Civil Engineer,—inserted in Mr Weale's work on the Theory, Practice, and Architecture of Bridges.

clay puddle, mixed with gravel and sand, or a portion of pounded chalk. All the water and soft material must then be got out of the dam. A steam-engine is used for clearing the space of water, and for keeping it dry during the progress of the building. The earth is removed from the coffer-dam by means of buckets, drawn up by windlasses erected on a temporary stage or platform across the dam, and the contents are discharged into barges alongside the dam. When the soft material has been removed, and the bottom is found to consist of hard gravel or clay, the building may be commenced, after sinking into it about two feet. Broad and large-bedded stones should be laid on the foundations, to give as much base with as few joints as possible for the superstructure to rest on. The first and second courses should be built with large stones, and, for the first few feet, with offsets, so that each course from the bottom may project all round at least six inches beyond the course immediately above. If, after the dam has been excavated, the bottom should appear unsound, piles must be driven all over the space to be occupied by the building, and extending about a foot beyond it. The piles may be of almost any kind of timber, such as Scotch fir, beech, elm, birch, &c. &c. eight or nine inches square, or round timber of this diameter: they should be driven in rows, from two to three feet apart, as far as they can be forced into the solid ground, or until each pile will not sink more than a quarter of an inch with twenty blows from a solid ram of 1,500 lbs. weight. When all the piles have been driven, their heads should be cut off quite level, and about a foot in depth being excavated between them, the space up to the level of the pile-heads should be filled with broken stones, grouted with good lime and sharp sand. A platform of oak, beech, or elm plank, from four to six inches thick, should then be placed across the pile-heads, and secured to them with spikes, bolts, or with treenails of hard wood. Another similar planking is usually laid across the first, and closely jointed thereto; and upon this upper platform the building, with brick or stone, is commenced. The masonry should be laid with offsets, and large stones should be used for the first and second courses.

This method of laying foundations by means of a coffer-dam and piling is very expensive. In situations where the river can be turned, a far less costly method may be adopted for giving stability to the unsound bottom. Mr. Hughes recommends that it be covered over entirely with cross-sleepers of Memel logs, and on these to lay a covering of planks closely jointed; while further security may be obtained by introducing inverted arches, above the planking, between the piers, and extending under each of the abutments. It will not be necessary to introduce a platform of timber to support the inverts, unless the ground be too soft to construct them upon it; and, in some cases, the platform without the inverts may be sufficient to carry the bridge. In many cases, concrete may be used as a substitute for piling, in order to secure a solid foundation. "The expense of laying a foundation of concrete, from four to six feet in depth, and extending about two feet round the space to be occupied by the building, ought, in all such cases, to be considered, and compared with the expense of piling, which will probably never be found more safe than a body of concrete, unless the bottom be so soft as to allow the concrete to sink into it, and thus entirely cease to support the building. For its durable and almost imperishable nature, concrete cannot be too much esteemed; and, besides being quite as safe, and, perhaps, more durable than piling, its cost will in most districts be found much less. Where the piers are to be built either of brick or stone, a great saving will be effected by the use of concrete underground, as the expense of this substance will in no case exceed one-third the price of any description of brick-work, and in some cases it may not cost more than a sixth."

It was Mr. Telford's practice, when the site of the foundations was unsafe, and the expense of driving piles through a very deep bed of loose material would be considerable, to lay an inverted arch between the piers and abutments. In other places, where the ground was more solid, but still doubtful, a pavement of broad stones was placed over the whole bottom, extending also under the abutments and wing-walls. These also were tied across the whole bottom by a row of the same description of broad-bedded stones, placed on edge; and this kind of pitching was often continued to the extent of the wing-walls, and then tied across by a row of the same stones, scabble-dressed, rough-shaped, jointed,

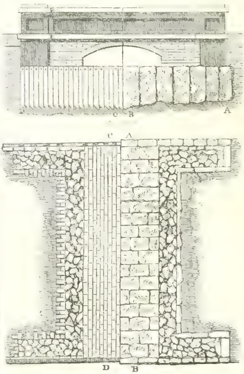


Fig. 283.

and set on edge, as at A B, Figs. 282, 283. When these stones could be procured in lengths of 6 or 7 feet, from 3 to 5 feet broad and from 6 to 9 inches thick, Mr. Telford preferred them to timber as a covering. Where large stones could not be readily obtained, he directed a pitched bottom to be formed with stones of about two feet superficial area, and not less than a foot deep. These were pitched endwise, close-jointed throughout their whole depth, and set with considerable care; and they were never allowed to be set on sand or any material that could afterwards be carried away by the water. This pitching was usually secured at the end of the abutments and wing-walls by a longitudinal sleeper, placed along the outside, with sheeting piles driven down in front to a depth of from six to ten feet, according to the nature of the bottom. This method is shown at C D, Figs. 282, 283.

Sandy foundations present a great variety. The sand may be rounded or angular, the latter forming what is called a *sharp* sand; or the particles may be minute, as in *fine* sand, or very large, as when the sand approaches the nature of gravel. Sandy soils are also distinguished from each other by the proportions they contain of clay, or other earthy matter, which, in combination with the sand, is termed *silt*. Fine sharp sand is usually found in currents sufficiently rapid to carry away the particles of earthy and other matters, commonly deposited with the sand in still waters. When the currents are still more rapid, the beds may consist of gravel and sharp angular sand, with no silt. The stronger the current, the coarser the gravel, and the smaller the proportion of sand mixed with it. A quicksand is formed by the action of water on a bed of this material, whether of a silty or pure sandy nature; and the danger of its giving way, when any weight is placed upon a quicksand, arises from its tendency to escape with the water, and pass from under the pressure. If this can be prevented, the foundation is a good one; for sand or silt, in a state of rest, is remarkably solid, the smallest vacuities being filled with it. Thus, a quicksand surrounded by a strong and close encaissement of piling would be perfectly safe as a foundation. When there is any danger of the sinking of a structure in consequence of the lateral shifting of the sand, the first part of the foundation should consist of a timber platform resting upon the sand, and of sufficient area to extend two or three feet on each side beyond the base of the structure to be raised upon it. It may be laid with sleepers, ten inches wide, and six inches thick, placed at the distance of three feet apart, from centre to centre: these must be closely covered with four-inch-thick planks, closely jointed, and secured to the sleepers with trenails.

In rivers where there is very little current, and the sand bottom has a covering of two or three feet of clay, or heavy gravel, which is not liable to be disturbed by floods or other causes, a building may safely rest on a sand bottom, without the accompaniment of a platform. In other cases, an artificial covering may be placed over the sand, and thus prevent its disturbance. Such a covering may be found necessary after the erection of a bridge, to prevent a sandy or silty bottom from being carried away by the current, which is often increased in velocity by the contraction of the water-way. By covering the bottom with clay for a distance of sixty or seventy feet above and below the bridge, and then overlaying the clay with stones varying in weight from 200 lbs. downwards, the whole artificial covering not exceeding two feet in thickness, the further wasting of the bottom may be prevented. This plan was successfully adopted by Mr. Rennie in the case of the Lary Bridge at Plymouth.

Some idea of the method of forming a coffer-dam may be gathered from the following details. Suppose a bridge-pier is to be erected in a tide-river, where there is 10 feet depth of water at the lowest spring tides, and that the bottom consists of 12 feet loose gravel and sand, with clay underneath. If we suppose the depth at high water to be not less than 28 feet, (making the whole depth, from the surface of high water, through the loose bottom, down to the clay, 40 feet,) the coffer-dam must be formed of four rows of piles, and the clay puddle will occupy three distinct spaces, or *puddle-walls*, between the four rows of piles. The outer row of piles, to be driven down to within a foot of low-water mark, and 5 feet into the clay, must be 28 feet long; the two middle rows, also to be driven 5 feet into the bottom, and to stand 3 feet above high-water mark, must be 48 feet long; the inner row, to be driven to about 11 feet above low-water mark, and 5 feet into the clay, will be 38 feet. The clear breadth between each two rows of piles to be 6 feet; the outer row of piles to be half-logs, of 12 inches by 6 scantling; the middle row to be 12-inch square logs, and the inner row to be 12 by 8 inches scantling. A double row of waling pieces to

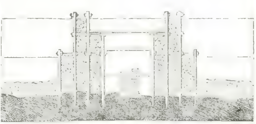


Fig. 284. TRANSVERSE SECTION OF COFFER-DAM.

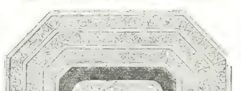


Fig. 285. PLAN OF COFFER-DAM.

be placed all round the top of the inner piles, as in Fig. 284, and to be connected by wrought-iron bolts, 1¼ inch square. Other lines of waling must be fixed round the coffer-dam, and connecting pieces must be introduced at intervals of 4 feet, from bolt to bolt, all round the dam. All the sand and gravel within the space to be occupied by the dam must be excavated, or it will permit the water to penetrate through; and this may be done by dredging before the piles are driven. In making the dam water-tight by puddling, clay alone should never be used, as it is subject to great changes, according to the alternations of heat and cold, drought and moisture. In very dry weather it will crack, and separate into irregular fragments, which will not unite again so as to form an adhesive water-tight substance. Mr. Hughes recommends 3 parts of pure clay, 2 of chalk, and 1 of fine gravel, as a good compound for filling the dam. These materials should be well mixed together, the chalk and clay chopped small, and no stone larger than a hen's egg allowed to pass amongst the gravel. It is usual in large dams to cover the top of the puddle with bricks, or with good strong gravel, grouted with lime, to the depth of a foot. All the piles used for the dam should be shod with wrought-iron shoes, not less than 10 lbs. each, and hooped with iron rings, three inches broad, and three-quarters of an inch thick, to prevent the timber from splintering or giving way under the driving. The following figures represent some varieties of iron shoes for piles.

Fig. 286.

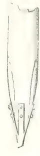


Fig. 287.

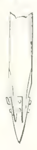


Fig. 288.

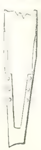


Fig. 289.

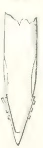
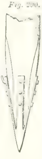


Fig. 290.



In constructing a coffer-dam, the first operation is to drive the *guide-piles*, so called from being the first in each row, and thus serving as guides to the rest. They are usually placed about ten feet apart, and the barge or other vessel containing the pile engine should be moored stem and stern alongside the line of the intended dam. A ringing machine, and wooden monkey, of about 800 lbs. weight, are first used for driving; and when all the guide-piles of one row have been fixed, the walings should be fastened to them, and the intermediate piles, ten in number, between each pair of gauge-piles, may be driven down. When the piles cease to sink, after repeated blows from the monkey, a heavy iron ram, of 1,500 or 1,800 lbs. weight, with considerable fall, may be used to complete the driving. When the heads of the piles get bushy or besomy, they should be squared off, that the force of the blow may not be deadened.

The old methods of pile-driving, which were very slow and toilsome, have been superseded by Nasmyth's Patent Steam Pile-driver, which may be easily made to perform 80 strokes per minute; and, in ordinary ground, piles of 14 inches square are driven at the rate of upwards of 10 feet per minute. The inventor says: "Instead of attempting to obtain high momentum from a small mass of iron falling from a great height, I employ the momentum resulting from a great mass falling with moderate velocity from a small height, (3 feet,) and, instead of having one blow per minute, I employ from 70 to 80 blows per minute. The result is that, while the pile is driven with ease and rapidity into the most rigid and resisting soil, the head of the pile is so little injured as to present a neater appearance after having been driven than at the commencement of the action. All this advantage arises simply from employing the mechanical force in its proper condition for the performance of the required duty. If we desire to split and shatter to splinters, let us give the blow from a small mass, travelling at the highest possible velocity; if, on the other hand, we desire to propel and push forward such a mass as a log of timber, let us do just the reverse, namely, give it a blow from a heavy mass, moving at a low velocity." The inventor justly remarks that, although we have equivalent mechanical forces in the case of

4 lbs. falling with a velocity of 1,000 feet per second,
and 1,000 lbs. falling with a velocity of 4 feet per second,

yet how very dissimilar are the effects of each, when

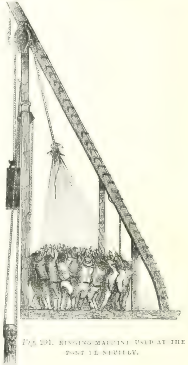
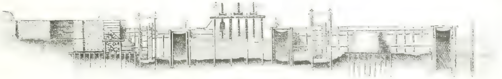


Fig. 291. RINGING MACHINE USED AT THE PONT DE NEUILLY.

employed to confirm and finish this [illegible] a pile.[1] [See STEAM HAMMER.]

A remarkable application of the science of pneumatics has been made by Dr Potts, in the construction of an apparatus for sinking foundations by means of atmospheric pressure, in deep water, on quicksands, mud, shingle, or bog. It consists in the use of hollow tubes, usually of cast-iron, of any size, and almost of any shape, which are sunk into their places by means of atmospheric pressure. The lower end of the tube is open, and being placed upon the ground, of whatever nature it may be, the air, water, or semifluid material in the inside is extracted by pumps, or by other means. When the more solid materials are removed, the air in the interior of the tubes is rarefied by placing them in communication with large vessels from which the air has been previously withdrawn, by means of a pipe and stopcock. As soon as the communication is effected, the air in the interior of the tubes rushes into the empty vessels, leaving the atmospheric pressure upon the pile-head without any counteracting resistance. If the strata to be traversed is of a yielding semi-fluid nature, they are also acted upon by the same cause, and flow up into the tube or hollow pile, which at the same time descends with corresponding rapidity. The materials thus introduced are removed, or, if the strata be more resisting, they are thrown out, so as to attain the greatest possible rarefaction of the air; and the operation is repeated until the piles are fully driven. A succession of tubes may be placed upon the first by means of flanges or other joints, so that they may be driven of any length required.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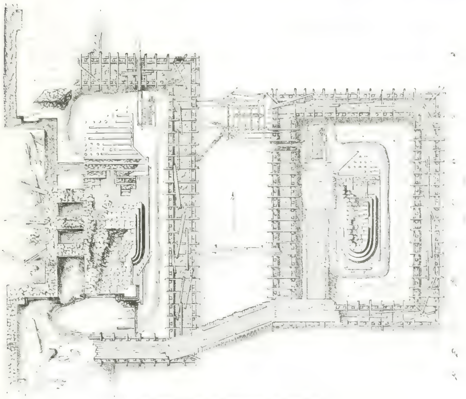
Fig. [illegible]—PLAN OF [illegible] AT [illegible].

The chief advantage of this system is, that no vibration is communicated to the ground, and the elasticity of the strata traversed is never brought into action. A remarkable illustration of its advantages in this respect occurred on the Goodwin Sands, where a tube 2 feet 6½ inches in diameter sunk to a depth of 32 feet 7 inches in 6 hours; whereas, a pile of iron 8 inches in diameter, could not be driven more than 13 feet, at which depth it required 46 blows of a monkey weighing 10 cwt., falling through 10 feet, to advance it one inch. In such sandy soils, and sometimes, also, in clay soils, it is necessary to drive common piles with the large or butt-end downwards, to prevent the elasticity from forcing them up again.

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[1] A [illegible] of this [illegible] in Mr D[illegible] work, entitled "[illegible] Machinist's Assistant," &c. Glasgow, [illegible] 1847.

These pneumatic piles have been used in the foundations of several railway-bridges. Those for Windsor Bridge were 5 and 6 feet in diameter; and, some years ago, Messrs. Fox and Henderson inserted in the foundations of the bridge over the Medway, at Rochester, cylinders 10 feet in diameter. With such colossal dimensions, they cease to be piles, and become, in fact, caissons. When the hollow cylinders have been sunk, and the earth which has risen up into them been removed, they are filled up with concrete, and thus made equivalent to solid columns.[1]

The accompanying section and plan of the coffer-dam at Neuilly, Figs. 292 and 293, will convey a general idea of the arrangements of coffer-dams. The arrows represent the direction of the stream, which was taken advantage of for turning large water-wheels placed in the river, the motion of which, being communicated to pump-machinery within the dam, raised the waters thereof, and discharged them by means of shoots over the piles into the river. The works at the left of the figures are the land abutments, dammed in on the river side, and containing also the first pier. The complete coffer-dam to the right shows the second pier in progress. Temporary bridges of planking connect the dams with the land.

2. *The piers and abutments.* In the construction of a bridge it must be nearly always desirable to have the smallest possible number of points of support. "Piers in a waterway intercept the current and impede the navigation; they are most troublesome and expensive to found and form, and are most exposed to injury when they are formed. The object of the bridge itself—a convenient road over—being properly provided for, and the permanence of the structure being sufficiently considered, it is not too much to say that the aim and end of the bridge-builder should be to reduce the piers to the smallest possible number, consistently with a due regard to economy. Of all the bridges over the Thames, at and near London, the suspension bridge at Hammersmith interferes least with the navigation of the river, and is least exposed to injury from the action of the current upon its points of support; these having to a certain extent, the effect of embankment-walls, which prevent the stream from spreading itself uselessly, if not injuriously, over a wide and shallow bed, and direct the current upon the mid-channel, whereby it is kept free and clear; whereas, the lumbering masses which support Putney Bridge obstruct the navigation, force the current into narrow rapids, which tend in every way to the destruction of the works themselves, and make the passage up the river dangerous. The laden barge of commerce and the double-banked barge of pleasure pass with or against the stream, and alike with ease and safety, under the tasteful and scientific creation which carries a convenient and agreeable road over, and leaves the water-way uninterrupted, while both are exposed to inconvenience and danger where the ugly piles of Putney and Battersea support narrow and inconvenient roadways over the dammed-up river. In like manner, the effect of Southwark Bridge, with its two well-formed piers of neatly-executed masonry, is hardly felt upon the river; whilst the multitude of wry-looking angular piers of Vauxhall Bridge, standing across a bend of the river, are with difficulty avoided by the heavy craft, which depend almost entirely upon the current for motion. These are timber and iron bridges, of various forms and modes of arrangement; and with the materials of which they are composed, no sensible inconvenience, and much less obstruction, should in any case have been imposed upon the navigation of the river. That neither obstruction nor inconvenience is necessary with even a bridge of masonry is shown by the new London Bridge, which contrasts advantageously, not alone with its predecessor, but with all the other stone bridges upon the river, in these respects. The infrequency of the piers, and their moderate bulk, together with the expanse and elevation of the arches, preserving the head-way almost unabated over a great part of the whole width of the water-way, show in these, as in other respects, an example of the highest degree of perfection in the practice of bridge-building. . . . Had Labelye and Mylne built with granite, their works could not have been executed with the funds at their disposal, respectively; but with granite, and the means of applying it, they would possibly, or they ought to, have occupied less of the water-way with obstructions; and, with the means at their disposal of raising the approaches, they would probably have avoided making the roadways upon their bridges so steep as to be always inconvenient, and sometimes dangerous." (*Hosking.*)

The danger of contracting the water-way by piers is shown in the case of Hexham Bridge, over the Tyne,

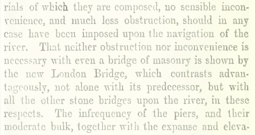

Fig. 294.

built by Smeaton. The piers were built upon a thin stratum of gravel which rested upon loose sand capable of yielding to the action of water, if once exposed to it. To prevent this exposure, the piers were furnished with rubble defences (Fig. 294), the effect of which was [illegible] to diminish the already contracted waterway, and to raise the flood-waters to the head requisite to scour it away, with the gravel under it, by which means the sand was exposed, and the piers at once undermined, so that the bridge fell. The river Tyne, in the part where the bridge stood, was about 530 or 540 feet wide, at the height of freshes or ordinary floods: this width the piers and abutments reduced one-third, leaving but 424 feet opening between the piers where they are thinnest, and the diminished width was further reduced below summer water-level by the greater substance of the piers at their footings, and by the defences of rubble packed around them, which had the effect of making an imperfect dam, or sunken weir, at every archway. "But the flood-waters had on previous occasions risen above bridge to the height of the springings of the arches without injury to the works, notwithstanding the pressure of a head of 3 feet of water, accumulated by the obstructions of the piers and their defences, and a scour arising from a velocity of from 800 to 900 feet per minute resulting from that head. Above the level of the springings, however, the arches themselves began to be immersed, and these in a rise of 3 feet in height above the springings, will have further diminished the water-way full 30 feet, when the pressure became sufficient to break up the crust of gravel that lay exposed between the toes of the rubble defences of the piers, to wash out the sand and loam from between the rubble, and to scour out a channel deep enough to compensate for the space that the piers of the bridge, with their defences, and the immersed haunches of the arches occupied." It is probable, in cases of this kind, if the bed of the river were deepened sufficiently to make the section of the water-way in the bays equal to the whole section of the bed or trough occupied by water before the erection of the piers, no danger would ensue. Under ordinary circumstances, the current will effect such deepening of itself; but while doing so, the piers are exposed to a great wearing action, which, in the case before us, proved fatal. Fig. 291 represents a longitudinal section of the central arch and its piers. The lower water-level is that of summer-water, and the top dotted line is the height above bridge of the flood which undermined and overthrew it.

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[1] Supplement to M. [illegible]

Mr. Hosking remarks, that the substance in thickness of which bridge piers may be built, must depend in a great degree upon the materials of which they are composed, the height to which it may be necessary to carry them, and the weight of the arches, upper works, and load; it being taken for granted that the workmanship is good, as the thickest piers, badly wrought and built, may be unable to bear the weight they are intended to carry, though piers of half their substance might be sufficient. "If the piers of Westminster and Blackfriars bridges had been one-eighth or one-ninth the span of the arches resting upon them, instead of one-fourth and one-fifth of that proportion, as they are respectively, it is not improbable that both these bridges would have failed. The late operations for the repairs to their piers have exposed workmanship of the worst kind; even in the outside or ashlar courses, stone chips and pieces of slate and even deal chips were commonly found packed and wedged in to compensate for the leanness of the stones in both beds and joints."

Some of the piers of Old London Bridge were larger than the original openings of the arches; they consisted of small rubble stones laid in lime-mortar, surrounded by a thin casing of squared stones. The Roman bridges were probably constructed in the same manner. In modern bridges, the piers consist wholly of squared stones, each course being of equal height quite through the body of the pier. The thickness ought to be regulated by the span and rise of the arches, combined with the height of the piers. At the bridge of Neuilly the thickness is only one-ninth part of the span from the springing of the arches. The height is regulated according to circumstances, attention being given to the highest point to which the waters have ever been known to have risen.

With respect to the shape of the piers, the portion which supports the arch is usually oblong with right lined parallel sides. Under low-water the pier increases in breadth to the foundation. The rate of increase is regulated by the nature of the foundation, and the proportions which the body of the pier bears to the span of the arches. In many modern bridges this increase is at the rate of three inches for every foot in height. Large offsets are convenient for supporting the centres, but three or four inches in the stonework is sufficient for that purpose, the wooden platform projecting considerably more around the pier. The ends of the piers should be provided with salient angles to act as *cutwaters*. Some recommend that the shape of the cutwaters should be triangular, and that they should differ in their size; and others, where heavy craft are navigated, consider circular cutwaters best calculated to resist the effects of concussion. The form of a gothic pointed arch diminishing to its apex, seems best fitted for the division of the stream and for resisting the impulse of heavy bodies.

The shapes of the points of the piers are various, such as acute-angled, right-angled, semicircular, or two segments of a circle intersecting each other. Telford preferred the second and fourth of these forms. These projecting points are usually diminished from the fronts of each side of the piers. Each course of stone around the outside should be laid header and stretcher alternately. The stretchers should be from eighteen inches to two feet in breadth, and the headers about one-third of the whole face, or each from three to four feet long. The upright, or end joints, should be correctly squared at least one foot in from the face, and in no part should be more than one inch in width. The interior, or filling-in stones, should be of equal height with the outside stones, and should have their upright joints not more than one inch wide: they should break joint at least one foot; the first and all succeeding courses should be laid flushed, with both their bed and upright joints in proper mortar. There should be an allowance for the thickness of the outside mortar joints of about one-eighth inch when compressed. All the joints should be run full of grout where there is any vacancy. The hardest and most perfect stones should be used for the projecting points of the piers, especially those on the upper side of the bridge. The points should be carried up at least to above high-water mark, and at that height to be usually finished by sloping them back to the face of the spandrels. The courses of stone may vary in thickness, eighteen inches being a good average.

The abutments are managed in the same manner as the piers, only their backing is generally made of good rubble stone laid in lime mortar. This rubble work must be levelled and grouted at the height of each course of square masonry, the whole to be properly bonded and connected together. If the bridge be wide, a buttress or counterfort should be placed behind the middle part of the abutment; it should be of rubble work well bonded into the body of the abutment, and having thin hoop-iron, laths, or half-inch boards laid in as they are carried up.

3. *The centres.* In the construction of an arch, a timber-framing called a *centre* or *center* (from the French verb *ceintre* or *cintre*), is necessary for supporting the voussoirs until they are keyed in. The centre must be strong enough to bear the weight or pressure of the voussoirs without any sensible change of form throughout the whole progress of the work, or fatal results may ensue, as in the case of a large arch erected over the river Derwent, on the line of the Glossop and Sheffield road. The men were proceeding to lay the keystone, when the centre gave way and fell with a tremendous crash into the river, causing the loss of several lives.

A centre should also admit of being easily and safely removed, and so designed that it may be erected at a moderate cost. In navigable rivers, where a certain space must be left for the passage of vessels, and in deep and rapid rivers, where it is difficult to establish intermediate supports, the frames should span the whole width of the archway. In other cases the framing may be constructed upon horizontal tie-beams, supported in several places by piles or frames fixed in the bed of the river.

Dr. Robison remarks that the general principles of carpentry furnish a rule for the construction of centres. To give the utmost possible strength to a frame of carpentry, every piece should be so disposed that it is subject to no strain but what either pushes or draws it in the direction of its length; and if we depend on timber alone for the strength of the centre, we must rest all on the first of these strains; for when the straining force tends to *draw* a beam out of its place, it must be held there by a mortice and tenon joint, which possesses but a trifling force, or by iron straps and bolts. Cases occur where it may be difficult to make every strain a thrust, and the best artists admit of ties; and indeed, where a tie-beam can be admitted connecting the two feet of the frame, no better security need be sought. But this may in some cases be inconvenient. In supporting the arch of a bridge, such a tie-beam would stop the passage of small craft up and down the river. It would often be in the water, and thus exposed to accidents by freshes, &c. Interrupted ties must therefore be employed, whose joint or meetings must be supported by something analogous to the king-posts of roofs. When this is judiciously done, the security is good. But great judgment is necessary in the disposition of the pieces. It is by no means an easy matter to decide whether a beam in a centre is in a state of compression or of extension. In some works we see pieces considered as struts and relied on as such, while they are certainly tie-beams, and should be secured accordingly. It is of great consequence not to be mistaken in this point; for in such case if the piece be stretched when we imagine it to be compressed, we are not only deprived of some support which was expected, but the expected support has become an additional load. To ascertain this point we may suppose the piers to yield a little to the pressure of the arch-stones on the centre frames. The feet therefore fly outwards and the shape is altered by the sinking of the crown. The frame must be drawn again for this new state of things, and we must notice what pieces must be made longer than before. All such pieces have been acting the part of tie-beams.

The centre has also to keep the arch in form: that is, while the load on the centre is continually increasing, as the masons lay on more courses of arch-stones, the frame must not yield and go out of shape, sinking under the weight on the haunches and rising in the crown, which is not yet carrying any load. The frame must not be supple; and must derive its stiffness not from the closeness and strength of its joints, which are quite insignificant when set in competition with such immense strains, but from struts or ties properly disposed, which prevent any of the angles from changing its amplitude. The strength and stiffness of the whole centre must be found in the triangles into which this frame of carpentry may be resolved. The strain which one piece produces on two others with which it meets in one point, depends on the angles of their intersection, and these are greater as an obtuse angle is more obtuse or an acute angle more acute. This suggests the general maxim, to avoid as much as possible all very obtuse angles. Acute angles which are not necessarily accompanied by obtuse ones, are not so hurtful; because the strain here can never exceed the straining force; whereas in the case of an obtuse angle it may surpass it in any degree.[1]

Centres are composed of separate vertical frames or trusses, placed from four to six feet apart, connected together by horizontal ties and stiffened by braces. When the frames have to span the whole width of the archway, the offsets of the stone-work afford a most substantial abutment for the support of the centre. There is generally one frame under each of the external rings of arch stones, and the intermediate space is equally divided by the intermediate frames. A bridge of three arches requires two centres; one of five arches three centres, and so on.

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[1] Robison, "System of Mechanical Philosophy," edited by Brewster.

In the designing of centres, it is important to determine the point at which the arch-stones first begin to press upon the centre, and also the pressure upon it at different periods of the formation of the arch. It has been found by experiment that a stone placed upon an inclined plane does not begin to slide until that plane has an inclination of 30° from the horizontal, and until a stone begins to slide upon its joint, or bed, it does not of course press upon the centre. When a hard stone is laid with a bed of mortar, it will not slide until the angle becomes 31° or 36°. A soft stone bedded in mortar will stand when the angle which the joint makes with the horizon is 45°, if it absorb water quickly, because in that case the mortar becomes partially set. The pressure may in general be considered to commence at the joint which makes an angle of 32° with the horizon. This angle is called the *angle of repose*, and if we consider the pressure to be represented by the radius, the tangent of this angle will represent the friction: and considering the pressure as unity, the friction will be 0·625. The next course above the angle of repose will press upon the centre, but only in a small degree; and the pressure will increase with each succeeding course, so that when the plane of the joint becomes so much inclined that a vertical line passing through the centre of gravity of the arch-stone does not fall within the lower bed of the stone, the whole weight of the arch-stone may be considered as resting upon the centre. Mr. Tredgold[1] has given a method of estimating the weight upon a centre at any period of the construction, or when any portion of the arch-stones is laid, as well as when the whole weight which it has to sustain is laid upon it.

As the pressure increases very slowly until the joint begins to make a considerable angle with the horizon, the strength of the centre should be directed to the parts where the strain is greatest. For example, at the point where the joint makes an angle of 44° with the horizon, the arch-stone only exerts a pressure of one-fourth of its weight upon the centre; where the angle of the joint is 58°, the pressure exceeds half the weight; but near to the crown, the stones rest wholly upon the centre. Now it is of course unnecessary to make the centre equally strong at each of these points, and if this were done there would not be the means of applying strength where it is really required, without interfering with ties and braces, which are only an incumbrance to the framing. When the depth of the arch-stone is nearly double its thickness, the whole of its weight may be considered to rest upon the centre, when the joint makes an angle of about 60° with the horizon. If the length be less than twice the thickness, it may be considered to rest wholly upon the centre, when the angle is below 60°, and if the length exceed twice the thickness, the angle will be considerably above 60°, before the whole weight will press upon the centre. When the arch-stones are small, the pressure upon the centre is greater than when they are large.

In order to make a centre sufficiently strong to support any part or the whole of the pressure, the strains must not act very obliquely upon the supporting pieces, and the magnitude of the parts must be proportioned to the strain upon them. In order to support any part without a sensible change of form, the parts of the centre must be so disposed, that the stress may prevent any part from rising instead of tending to rise; for there is this danger in large arches, when the arch-stones are laid to a considerable height, that they often force the centre out of form by causing it to rise at the crown, rendering it often necessary to load the centre at the crown to prevent such rising.

When arches are of small span the centres are easily managed, and when it is possible to obtain intermediate supports without great expense, large centres are not difficult. The centering of Conon Bridge, of which the span is 65 feet and the rise 21.8 feet, is a good example of this kind of construction: it was designed by Mr. Telford.

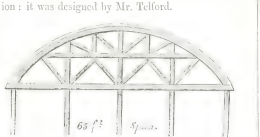

Fig. 295.

Fig. 296, is the centre designed by Smeaton for the Coldstream Bridge. The scantlings are contrived to suit the general scantlings of timber so as to save labour, and to have the timber in as useful a state as possible when it had served its purpose. "What I had in view," he says in his Reports, "was to distribute the supporters equally under the burden, preserving at the same time such a geometrical connexion throughout the whole, that if any one pile or row of piles should settle, the incumbent weight would be supported by the rest. With respect to the scantlings, I did not so much contrive how to do with the least quantity of timber, as how to cut it with the least waste; for as I took it for granted the centre would be constructed of east country fir, I have set down the scantlings, such as they usually are in whole balks or cut in two length-

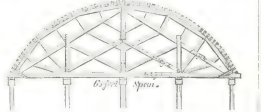

Fig. 296.

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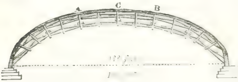
(1) Elementary Principles of Carpentry. London, 1820.

wise." The arch which this centre carried was of stone, its chord 60 feet 8 inches, versed sine 18 feet, and width across the vertex 25 feet. The centering consisted of 5 frames or ribs.

Where intermediate supports cannot be obtained, centres require more care in the construction. The placing of a load upon the haunches must have a tendency to raise the centre at the crown, unless the frame be so contrived that it cannot rise there under the effect of any force that it may have to sustain at the haunches. In some of the centres constructed by the French engineers, there was a change of form with every course of stones that was laid upon them. Thus in the centre designed by Perronet, for the bridge of Neuilly, Fig. 297, it is obvious that such a centre loaded at A and B must rise at C, and the timbers being nearly parallel, the strains produced by a weight resting on any point must have been very great, and the consequent yielding at the joints considerable. "It is a kind of framing well enough adapted to support an equilibrated load, distributed over its whole length; but is one of the worst that can be adopted for a centre, or for supporting any variable load. It must have consumed an immense quantity of timber, and yet without the advantage of connexion. The quantity is crowded into so small a space that it has a light appearance, and consequently has obtained the approbation of those who are incapable of penetrating further than the apparent surface of things they pretend to examine. The centres for the bridges of Nojent, Cravant, St. Maxence, and Nemours, were designed on similar principles, and were found to be equally defective." Fig. 298 represents the centre of Waterloo Bridge, designed by Mr. Rennie, [illegible] better disposition of its timbers, a load at A could not cause the centre to rise at C without reducing the length of the beam DE, and the one opposite it. There is an excess of strength in some of its parts, and it is complicated in the extreme; but on the whole it is a very judicious combination." Where timbers meet at an angle, it is desirable to let them abut into a socket of cast-iron, as was done in this case, Fig. 298. If possible the principal beams should abut end to end, and intersect one another as little as possible, as every joining causes some degree of settlement, and halving the timbers together destroys nearly half their strength.



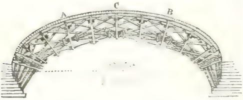
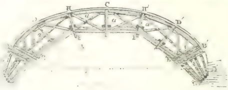


Fig. 299, is a design for a centre by Mr. Tredgold. "Let the built beams EF, FF′, and F′E′ be each trussed and abut against each other at F and F′; then it is obvious that when the loads press equally at DD′, they will have no tendency to raise the beam FF′ in the middle, unless it be not sufficiently strong to resist the pressure in the direction of its length: and as it is easy to give any degree of strength that may be required, a centre of this form may with a little variation in the trusses be applied with advantage to any span which will admit of a stone bridge. When timber is not to be had of sufficient length, the beams EF, FF′, and F′E′ may be built in the manner directed for building beams." These beams constitute the chief support; the arch is an ellipse, and consequently a considerable part of it will bear almost wholly on the centre. But if we take the whole weight of the ring between D and C and consider it to act in the direction HF at the joining F, it will be the greatest strain that can possibly occur at that point from the weight of the arch-stones. Produce the line HF to *f* and let *hf* represent the pressure; draw *he* parallel to the beam EF. Then as *hf* represents the pressure of the arch between D and C, *he* will be the pressure in the direction of the beam FE; and *ef* the pressure in the direction of the beam FF′: and these beams must be of such scantlings as will sustain these pressures. Let the weight of the arch from H to H′ be estimated, and if two-thirds of this weight be considered to act at C in a vertical direction, it will be the greatest load that is likely to be laid at that point, and the dimensions for the parts of the truss FCF′ must be found so as to sustain that pressure. The frame EDF may be calculated to resist half the pressure of the arch-stones between B and H. From D to C the whole weight of the arch-stones together with the weight of the centre itself may be considered as acting in a vertical direction at E, and the supports at GE should be sufficient to sustain the action of this pressure.



Perronet's general maxim of construction was to make the truss consist of several courses of separate trusses, independent as he supposed of each other, and thus to engage the joint support of them all. This centre consisted of a number of struts, set end to end, and forming a polygon. The trusses were so arranged that the angles of one were in the middle of the sides of the next, as when a polygon is inscribed in a circle, and another of the same number of sides is circumscribed by lines which touch the circle in the angles of the inscribed polygon. By this construction the angles of the alternate trusses lie in lines pointing towards the centre of the curve. King posts were therefore placed in this direction between the adjoining beams of the trusses. These king posts consisted of two beams, one on each side of the truss, and embraced the truss beams between them, meeting in the middle of their thickness. The abutting beams were mortised half into each half of the post. The other beam, which formed the base of the triangle, passed through the post, and a strong bolt was driven through the joint and secured by a key or a nut. In this manner the whole was united, and it was expected that when the load was laid on the uppermost truss it would all butt together, forcing down the king posts, and therefore pressing them on the beams of all the inferior trusses, causing them also to abut on each other, and thus to bear a share of the load. This method of construction is the invention of Perrault. Its merits are fully discussed by Dr. Robison in the first volume of his System of Mechanical Philosophy.

This construction, somewhat modified, was used by Perronet for the centering of the Bridge of Neuilly. The arch has 120 feet span and 30 feet rise, is 5 feet thick, and is remarkable for the flatness of its crown. The frames of the centering were 6 feet apart, and each carried an absolute load of 350 tons. The strut beams were 17 by 11 inches in scantling. The king posts were of 15 by 9 each half; and the horizontal bridles which bound the different frames together in five places were also 15 by 9 each half. There were 8 other horizontal binders of 9 inches square. As the stiffness of the framing depended on the transverse strength of the beams, care was taken not to weaken them by bolts. But notwithstanding this, the framing sunk upwards of 13 inches before the key-stones were laid; and during the progress of the work the crown rose and sunk by various steps as the loading was extended along it. When 20 courses were laid on each side, and about 16 tons laid on the crown of each frame, it sunk about an inch. When 16 courses were laid and the crown loaded with 50 tons, it sunk about half an inch more. It continued sinking as the work advanced, and when the key-stone was set it had sunk $13\frac{1}{4}$ inches. But this sinking was not general; on the contrary, the frame had risen greatly at the haunches, so as to open the upper part of the joints, many of which gaped an inch, and this opening of the joints gradually extended from the haunches towards the crown, in the neighbourhood of which they opened on the under side. This evidently arose from a want of stiffness in the frame. But these joints closed again when the centres were struck.

Fig. [illegible]—CENTERING OF THE PONT DE NEUILLY.

Dr. Robison remarks that the movements and twisting of this centre seem to indicate a deficiency not only of stiffness, but of abutment among the truss beams. The whole was too flexible because the angles were too obtuse. This arises from their multiplicity. Indeed, this centre should have consisted of fewer pieces, and their angles of meeting been proportionally more acute.

Dr. Robison gives by way of favourable contrast the details of Mr. Mylne's centre used for the arches of Blackfriars Bridge. The span of the arch is 100 feet and its height from the spring about 43. The leading maxim in this centre seems to be, that every part of the arch shall be supported by a simple truss of two legs resting one on each pier. The exterior joints are strengthened and the ring made as stiff as possible by apron pieces, from the ends of each of which proceed the two legs of the trusses. These legs are 12 inches square: they are not of an entire piece, but of several, meeting in firm abutment. Some of their meetings are secured by the double king posts, which grasp them firmly between them, and are held together by bolts. At other intersections the beams appear halved into each other; a practice which must weaken them and would endanger their breaking by cross strains, if it were possible for the frame to change its shape. But the great breadth of this frame is an effectual stop to any such change. No sinking or twisting was observed during the progress of the mason work. Three points in a straight line were marked on purpose for this observation, and were observed every day. The arch was more than 6 feet thick, and yet the sinking of the crown before setting the key-stones did not amount to one inch. This centre employs more timber than Perronet's, but is in every way stronger.

But with every care in the construction of centres there is always a sinking in the crown of the arch. Dr. Robison describes this in his peculiarly lucid manner. He says:—"By gradually withdrawing the centering, the joints close, the arch-stones begin to butt on each other and to force aside the lateral courses. This abutment gradually increasing, the pressure on the haunches of the centering is gradually diminished by the mutual abutment, and ceases entirely in that course which is the lowest that formerly pressed it: it then ceases in the course above, and then in the third, and so on. And in this manner not only the centering quits the arch gradually from the bottom to the top, by its own retiring from it, but the arch also quits the centering by changing its shape. If the centres were now pushed up again, it would touch the arch first at the crown; and it must lift up that part gradually before it came again in contact with the haunches. It is evident therefore that an arch, built on a centre perfectly suited to equilibration, will not be in equilibrio when the centering is removed. It is therefore necessary to frame the centering in such a manner, (by raising the crown,) that it shall leave the arch of a proper form. This is a very delicate task, requiring a previous knowledge of the ensuing change of form. But suppose this attained, there is another difficulty. While the work advances, the centering is warped by the load laid upon it, and continually increasing on each side. The first pressure on the centering forces down the haunches and raises the crown. The arch is therefore less curved at the haunches than is intended: the joints however accommodate themselves to this form, and are close and filled with mortar. When the masons approach the middle of the arch, the frame sinks there and rises up at the haunches. This opens all the joints in that place on the upper side. By the time that the key-stones are set, this warping has gone further; and the joints are open on the under side near the crown. It is true we are here speaking of an extreme case when the centering is very flexible, but this occurred to Perronet in the two great bridges of Neuilly and of Mantz. In this last one, the crown sunk above a foot before the key was set, and the joints at the haunches opened more than an inch *above*, while some nearer the crown opened nearly a quarter of an inch *below*. In this condition of things it is a delicate business to strike the centering. Were it removed in an instant, all would probably come down, for the arch-stones are not yet abutting on each other, and the joints in the middle are open below. "Perronet's method was to begin to detach the centering at the very bottom on each side equally, where the pressure on the centering is very slight. He cut away the blocks immediately under each arch-stone, and proceeded gradually upwards in this way, till all was detached that had been put out of shape by the bending of the centering. This being no longer supported, sunk inward till it was stopped by the abutment which it found on the arch-stones near the crown, which were still resting on their blocks. During part of this process, the open joints opened still more, owing to the removal of the load from the haunches of the centering. This allowed the crown to sink still more, by forcing out the arch-stones at the haunches. He now paused some days, and during this time the two haunches, now hanging in the air, gradually pressed in toward the centering, their outer joints closing in the meanwhile. The haunches were now pressing pretty hard on the arch-stones nearer the crown. He then proceeded more slowly, destroying the blocks and bridgings of these upper arch-stones. As soon as the support of one was destroyed, it immediately yielded to the pressure of the haunch; and if the joint between it and the adjoining one toward the crown happened to be open, whether on the upper or the under side, it immediately closed on it. But in this way it was found that every stone sank a little while it leaned on its neighbour, tending to produce the deformity of a ragged soffit. They were therefore not allowed to sink so much. In the places of the blocks and bridgings which had been cut away, small billets were set standing on their ends between the centering and the arch-stones. These allowed the pendulous arch to push toward the crown without sensibly descending; for the billets were pushed out of the perpendicular, and some of them tumbled down. Proceeding in this way, he advanced to the very next course to the key-stone on each side, the joints closing all the way as he advanced. The detaching the three uppermost courses from the centering was most troublesome; for the whole elasticity of the centre was trying to unbend and pressing hard against them. They were found to be lifted up; for the joints beyond them, which had closed completely, now opened again below: but this was finished in one day, and the centre sprung up 2 or 3 inches, and the whole arch sunk about 6 inches. This was an anxious time," says Dr. Robison, "for he dreaded the great momentum of such a vast mass of matter: it was hard to say where it would stop. It stopped, however, very soon, settling slowly as the mortar was compressed, and, after one or two days, settling no more. This settling was very considerable, both in the bridge at Neuilly and in that at Mantz. In the former, the sinking during the work amounted to 13 inches. It sunk 6 inches more when the blocks and bridgings were taken out, and 1½ when the small standards were destroyed, and 1¼ more next day; so that the whole sinking of the pendulous arch was 9½ inches, besides what it had sunk by the bending and compression of the centering. In fact, the whole sinking of this arch was 23½ inches. The sinking of the arches at Mantz amounted in all to 20½ inches, of which 12 inches was owing to the compression and bending of the centering."

After the centres of the arches of the Pont de Neuilly had been eased in the manner described, the principal timbers were suddenly removed, in the presence of the king (Louis XV.), the court, and a vast assemblage of spectators, collected together, as Perronet modestly observes, in consequence of the presence of royalty. The whole formed a sort of *coup-de-spectacle* of a very striking kind. Perronet describes minutely the arrangements made for the occasion, and gives an animated view of the scene as it appeared on the 22d September, 1771. To render the manœuvre more interesting, it was arranged that all the frames of each arch should be made to fall in succession, within a few minutes. For this purpose, ropes were attached to the frames, and were drawn tight by capstans, placed at some distance on the land (see Fig. 301). Nine men were placed at each capstan, one of whom superintended the arrangement of the ropes, and another directed the motion of the capstan, each turn of which was regulated by the sound of drums. In this way the frames were all pulled down in 3½ minutes. The fall of such a vast quantity of timber, which weighed at least 720 milliers for each arch, caused the water to rise in foam upon the bridge. The arches were thus com-

[illegible] STRIKING [illegible] OF THE ARCHES OF THE [illegible]

pletely exposed to view, and their light appearance and bold construction were generally admired. The string-courses, parapets, and masonry above were yet to be added. In this unfinished state of the bridge, it occasioned great surprise to see all this timber framing suddenly fall down, which, an instant before, seemed necessary to the support of the arches. The king, in returning to Marly, passed in a carriage over the new bridge. The spectacle came off without any accident, and a medal was struck to commemorate the occasion

4. *The arches.* When the centres have been placed, and properly secured, the setting of the arch-stones is the next step. The masonry of the piers and abutments near the springing is properly adjusted, and, in some cases, immediately below the commencement of the curvature, it is usual to lay a coping, string, or cordon, the slight projection of which covers any small inaccuracy in setting out or carrying up the abutments and piers. The form and dimensions of the arch-stones are of the greatest importance. These have been greatly varied in different works. The French have used very deep arch-stones, which, in conjunction with their wide mortar-joints, has contributed to the great sinking of their arches. The depth of the arch-stones at the crown in the bridges of Orleans and Mantes is 6 feet. In Blackfriars and Westminster it is 5. Mr Telford thinks from 3½ to 4 feet a good length. "When they are longer, as the beds can scarcely ever be worked and set exactly true, they are apt to break when the weight comes upon them; and when shorter, there is not sufficient space to overlap or break the joints properly. Each course should be of equal thickness quite through between the headers. The thickness of each course should be from one-third to one-half their depth, and they should be chamfered or rusticated along the bed-joints, and also the end of the quoin heads. The beds should be worked as true as possible for the whole breadth of each stone; the [illegible] of which bears on every other portion. Each stone should be laid so as just to swim in the mortar, and be struck with a maul two or three good blows. The joints of the headers should be of equal thickness with those of the other stones in the same course. Inexperienced masons, by laying the headers with thinner joints, for show of fine-work, frequently create an unequal pressure, which bursts or splinters the headers before the interior arch-stones come to an equal bearing." In setting the arch-stones, each course must point in the direction of the radius: and, that the workman may do this correctly, the thickness of each course should be marked upon the outer ribs, and its line of direction upon the lower part of the beams of the same ribs. The courses must also be carried equally on each side of the centre, and the masonry over the solid part of each pier in the spandrels must also be carried up. It is sometimes necessary to place a temporary weight upon the crown of the centre, until the load approaches the middle. This is done in Fig. 300. If the arches are flat, one side of the pier must not be exposed until it have sufficient weight upon it, or is guarded by resistance on the opposite side. At the bridge of Mantes, a neglect of this precaution caused one of the piers to be pushed 4½ inches out of the perpendicular. By loading the opposite side, it was made to return 2¼ inches.

The keystones should be driven with moderate force, so as to fill their places firmly. When this is done, all the back and end joints of the whole arch should be carefully examined, and all vacancies run full of mortar, and firmly wedged with slates. The whole should then be left for some time to dry and get hard. Meanwhile, the masonry should be brought up in the spandrels to the level of about one-fourth of the rise of the arch. This was formerly, and is now, in some cases, of rubble-work. The outside stones in the part over the pier are carried up to the same height, but close to the arch-stones they are stepped or racked back, and so left until the centre is removed, because, if laid close up to the back of the arch-stones, the least sinking of the arch would cause a fissure.

When the centres are removed, the soffit of the arch is carefully examined, and the joints pared, cleaned out, and pointed. The chamfered or rustic joints prevent the edges from chipping, and cover any trifling inequality, so that the cross joints only require paring.

5. *The spandrels and wing-walls.* The spandrels of a bridge are the spaces between the haunches of an arch and its vertex at the extrados of the roadway. When the arches are completed, the points of the piers are brought up and finished, at some distance above high-water mark, by sloping them back to the face of the spandrel, in a triangular or circular form, or otherwise disposing them to receive columns, pilasters, or turrets. The latter act as buttresses, as well as ornaments, and contribute to the stability of the superstructure. The spandrels are finished in various ways: in some of the old bridges they were filled up with earth or gravel. In small bridges, the masonry should be brought up to the level of about one-fourth of the rise of the arch, and then be sloped up to the top of the back of the arch-stones, and the remaining space filled up with gravel or stone rubbish. In large French bridges they have been filled up entirely with rubble masonry; but Mr. Telford objects to this as throwing unnecessary weight upon the arches. To remedy this, openings have been made quite through, as in Fig. 294, and kept open or concealed, or vaults have been constructed, to lighten the piers which sink, or those adjacent to them. Fig. 302 shows the arrangement of the spandrels in the Orleans Bridge, and Fig. 303 that in Blackfriars Bridge. But, as these arches are easily deranged by any settlement of the main arch, a better plan is to build walls longitudinally, 2 or 3 feet apart, and from 18 inches to 3 feet in thickness: founded upon the solid rubble masonry, and increasing in length as they advance in height, they rest upon and abut against the backs of each row of arch-stones, and act as struts between them. These walls are kept steady by laying long stones occasionally across from one wall to another. The outside spandrel walls, running parallel with these, and being connected with them by long stones, become a part of the general frame. These walls are carried up to near the level of the top of the arch-stones, where they are covered with two rows of flat stones, or the openings are arched over. Small openings are made in the walls upon the top of the rubble masonry, through which any water that may fall into the spandrels is conducted to one point, where it issues through a pipe inserted in the arch-stones.

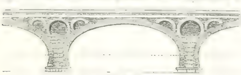


Fig. 302.

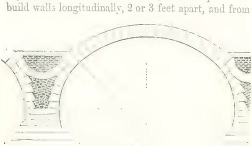


Fig. 303.

The outside walls are usually made thicker than the interior: they are faced with square masonry, and have a rubble backing; the whole thickness being about one-fifth of its height. When these walls are very high, a wall is also built along the middle of the piers and abutments which cross each other, and into which they are tied by bond-stones or pieces of timber laid at about every six feet in height. When these spandrels have been brought up to the level of the top of the arch-stones, they are dressed into the slope which it is proposed to make the roadway. Here there is usually laid a cordon and cornice, extending along the whole of the arches, spandrels, and wing-walls. Its upper course should be of sufficient breadth to allow for the projection, and to pass quite through under the parapet, which, by standing upon it, will keep it secure. The upper side of the projecting part should have a slope or weathering, to throw off the water.

The wing-walls behind the abutments are sometimes laid at the same depth as the abutments, and are similarly secured by piles and platforms. If the ground be firm, they are founded by steps, rising up as they retreat. This saves much masonry. Their thickness is from about one-fourth to one-fifth their height. When very long and high, a cross-wall should be built, reaching between them, into which they should be tied. The wing-walls should terminate in newells or pilasters.

6. *The parapets* usually consist of a plinth, dado, and coping. They are made from 3½ to 6 feet in height above the footpaths or roadway; but 4 feet 4 inches is sufficient for protection and decoration, and is not too high to obstruct the view. The dado, or middle member, is about 10 or 12 inches thick, but sometimes more; the plinth so much more than this as to leave an offset of about an inch on each side. The coping is usually made to slope each way from the middle. Balustrades are sometimes introduced instead of the dado; and in some cases, as where a bridge is exposed to violent gusts of wind, there are only half-balusters on the outside, the inside being solid.

7. *The roadway.* Gauthey remarks that most of the bridges erected before the eighteenth century were built with a view to economy, both with respect to the style of building and the degree of breadth allotted to them, since the most considerable scarcely allow room for two carriages to pass abreast. The bridges of Paris are for the most part very wide; but this extent was given to them solely with a view to erect two rows of small houses on their sides,—a circumstance which must naturally have produced a

very narrow thoroughfare. In modern bridges, the convenience for traffic is very properly the first consideration; a proper space being allowed for foot passengers, and another and larger space for horses and wheel carriages.

When the spandrels have been covered by arches or flat stones, the foundations for the footpaths are built with rubble-stone for the outside curbing. This should be of hard stone, set in lime-mortar. The space between the curbing and the parapets should be paved with hard flag-stones, laid in lime-mortar upon a bed of coarse sand or clean gravel. The breadth of the footpaths may vary from 3 to 6 feet, or more. If the carriage-way is to be paved, there should be laid upon the covering of the spandrels and over the top of the arches a bed of gravel, mixed with loam, from 12 to 18 inches in thickness, worked with water into the consistence of mortar. When this has become moderately firm, squared paving-stones are set and well beaten, making a curve across the road of 6 inches in 24 in breadth, and that curve should be terminated by sinking 4 inches more in the distance of 2 feet from the inclined plane formed along the outer edge of the curbing-stones. But if the roadway be only of gravel, it must be laid 22 inches in depth in the middle, and 18 inches near the sides. The gravel should be mixed with a little loam, to consolidate it, and exclude water. A gutter of small squared stones should be formed on each side of the roadway, to carry off the water. This in all cases should be conducted beyond the extremity of the wing-walls, and got rid of in covered drains or sewers.

Respecting the decorations of a bridge, Mr. Telford sensibly remarks :—"The decorations should be varied according to the situation and accompaniments. In the country, the utmost simplicity consistent with distinguishing the essential parts, should be preserved; and even in the most splendid cities, or adjacent to palaces, all decorations should be kept perfectly subservient to, and in unison with, the essential parts. The neglect of this is a frequent error in designing bridges. Columns and entablatures, though proper in a Grecian temple, are ill suited to an edifice where forms unknown to the Greeks are the leading features. As columns can only be placed over the piers and abutments, the entablature, intended to represent beams of timber, cannot be supposed to be wholly upheld by supports placed at such great distances from each other. And the introduction of columns, in place of carrying up the piers, deprives the superstructure of powerful buttresses, in situations where they would prove very beneficial. The affectation of preserving the entablature upon a perfect level, has led to making the roadway along the bridge also level, which is nothing less than constructing, at a vast expense, a piece of road, more imperfect than what is formed by the common labourer in the open country; and besides, this mode of construction gives an appearance of feebleness to the outlines of a bridge."[1]

No. of reference to Figure [illegible]	Name and Situation of Bridge.	Number of Arches.	Clear Waterway.	[illegible]	Width of Bridge between Parapets.	Form of Principal Arch.	Dimensions of Centre Arch.					Material.	Date of Erection.	Architect or Engineer.
							Span.	[illegible]	[illegible]	[illegible]	[illegible]			
			Feet.	Feet.	Feet.		Feet.	Feet.	Feet.	Feet.	Feet.			
1	Vieille Brioude, over the Allier	1	[illegible]	..	16 0	Circular ...	183 25	[illegible]	[illegible]	[illegible]	...	Tufa ...	[illegible]	Grenier and [illegible]
2	Bridge of the Holy Trinity, over the Arno, at Florence	[illegible]	[illegible]	[illegible]	[illegible]	Slightly elliptical	[illegible]	[illegible]	[illegible]	2.75	20	White marble..	[illegible]	B. Ammanati
3	Pont-y-pryddd, over the Taff	1	[illegible]	...	...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	...	Sandstone...	[illegible]	[illegible]
4	Bridge of Mantes, over the Seine	[illegible]	[illegible]	[illegible]	[illegible]	False ellipse ...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Sandstone and [illegible] stone	[illegible]	Perronet and Hupeau.
	Blackfriars Bridge, over the Thames	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	[illegible]	[illegible]	[illegible]	[illegible]	Portland stone	1771	Mylne.
5	Neuilly Bridge, over the Seine	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.25	13.83	Sandstone and stone	[illegible]	Perronet.
6	Bridge of St Maxence, over the Oise	[illegible]	[illegible]	240	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	... ...	1784	Idem.
7	Waterloo Bridge, over the Thames	[illegible]	[illegible]	[illegible]	41 6	Elliptical	[illegible]	[illegible]	[illegible]	[illegible]	20	Granite ...	1816	Rennie.
8	Gloucester Bridge, over the Severn	[illegible]	[illegible]	..	[illegible]	Idem ...	[illegible]	[illegible]	[illegible]	[illegible]	...	Sandstone ...	1827	Telford.
9	London Bridge, over the Thames	[illegible]	[illegible]	[illegible]	[illegible]	Idem ...	152	[illegible]	[illegible]	[illegible]	[illegible]	Granite ...	1831	Rennie.
10	Bridge over the Dee, at Chester	1	[illegible]	...	[illegible]	Circular ...	200	42	140	[illegible]	...	Sandstone ...	1833	Hartley.
11	Bridge carrying the Great Western Railway over the Thames at Maidenhead	[illegible]	[illegible]	[illegible]	[illegible]	Ellipse ...	[illegible]	[illegible]	[illegible]	5.25	23	Bricks laid in cement	[illegible]	Brunel.

The above Table, from Mr. Law's "Rudiments of Civil Engineering," contains the proportions and dimensions of some important bridges in Europe: it gives the radius of curvature of the main arch at its soffit, the depth of the keystones, and the materials of which they are composed. In these, as in most other examples, the form of the arch is either circular or elliptical; but the latter is now generally preferred, as the elliptical arch can be made of any height to the same span, or of any span to the same height, while, at the same time, its haunches are sufficiently elevated above the water, even when it is rather flat at the top,—a property which the other curves used for bridges do not possess in the same degree. This property is also the more valuable because, after the centre is struck, the arch settles more about the haunches than the other parts, by which the other curves are reduced near to a straight line at the top. Elliptical arches also look bolder, and are really stronger, although they require less materials and labour than the others.

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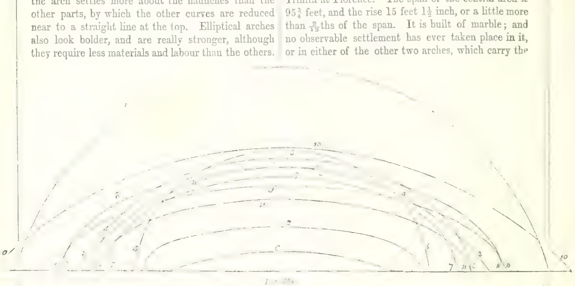
[1] From a valuable article on Bridge-building contributed to the Edinburgh Cyclopaedia by Messrs. Telford and Nimmo, to which the writer of this article is indebted for many useful suggestions.

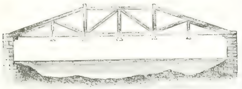
The flattest stone arch of large size, of which the tangent of the curve at the springing is at right angles to the chord or span, is in the bridge of the Trinità at Florence. The span of the central arch is $95\frac{3}{4}$ feet, and the rise 15 feet $1\frac{1}{2}$ inch, or a little more than $\frac{2}{13}$ths of the span. It is built of marble; and no observable settlement has ever taken place in it, or in either of the other two arches, which carry the thrust up to the abutments. The flattest brick arches of large size are those of the bridge that carries the Great Western Railway over the Thames, at Maidenhead. These are semi-elliptical in form, and of 128 feet span, and $24\frac{1}{2}$ feet rise. The abutments are stepped on raking benches on the chalk stratum upon which they stand; and the resistance thus obtained appears to be sufficient. Mr. Law remarks, that, taking into consideration the materials of which it is composed, this bridge is certainly the boldest which has ever been constructed, the actual pressure at the crown of the arch being about one-third of that which would begin to injure the cohesive strength of the material of which it is composed. "And although the construction of this bridge has shown that it is practicable to approach much closer to the load which would cause failure than had before been considered safe, it is questionable how far prudence would warrant such an approach in ordinary cases; especially when we consider how many accidental circumstances may deteriorate the stability of the arch, to guard against which, it seems desirable that a much wider margin should usually be given, and that the greatest load upon the keystone should not be greater than $\frac{1}{20}$th of that which would *begin* to crush its material, in bridges exposed to only ordinary traffic; and in those which are continually exposed to the tremour and vibration occasioned by a continuous and very heavy traffic, not more that $\frac{1}{30}$th."



SECTION IV.—ON TIMBER BRIDGES.

The oldest wooden bridge on record is the bridge of Sublicius, which existed at Rome 500 years B.C. It is celebrated for the combat of Horatius Cocles, a Roman knight, who saved the city by his noble defence of this bridge. It is stated to have been put together without iron or nails. A wooden bridge was erected by Julius Cæsar for the passage of his army across the Rhine. The passage was effected ten days after they began to carry the timber for its erection. The bridge built by Trajan over the Danube appears to have been of timber, except the piers, which were of stone. The roadway seems to have been supported by three concentric curved ribs of timber, connected by radial pieces. There were 20 or 22 stone piers, and each wooden arch was above 100 feet span.

In the middle ages, when men began to establish bridges on the passages over the principal rivers, it was customary to erect piers 15 to 20 feet apart, consisting of one or more rows of piles. They were defended by a kind of jetty to break the ice, which also served to protect them from the shock of bodies borne down by the current; frequent repairs were, however, required, and the accumulation of matters against the piles blocked up the water-way, and the bridge became incapable of resisting the pressure of water in the time of high floods. In these early times of modern bridge-building, abundance of material was used, without much skill in its arrangement; but in places not subject to floods, and in situations where the piers could be kept light, more elegant structures were erected. A bridge built by Palladio over the Brenta, near Bassano, is a good example of this kind of bridge. This great architect has given several designs for bridges, which have been adopted in later times. He appears to have been the first among the moderns who attempted that species of construction which renders numerous piers unnecessary, thereby avoiding the shock to the timberwork of bodies carried down by the current. His bridge over the torrent of Cismone, near Bassano, Fig. 305, was of this kind, with a span of 105 feet.



Another of his designs, Fig. 306, is a system of what

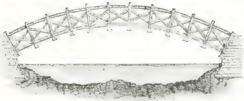


Fig. 306.

may be termed *framed voussoirs*, similar to the arch-stones of a stone bridge,—a principle that has since been successfully adopted, both in timber and in iron bridges.

One of the best modern methods of construction is that of forming curved ribs for the support of the roadway. This method, introduced by Mr. Price, is thus described by Tredgold. "He proposes the curved rib to rise about one-sixth of the opening, and to divide it into a convenient number of equal parts, according to the span, or to suit the lengths of the timber. For a bridge of 36 feet span, he proposes to make the ribs of oak, in five lengths, and 3 inches in thickness; each rib to consist of two thicknesses, one 12 inches deep, and the other 9 inches deep; the joints crossed, and the thicknesses keyed together with wooden keys. Two of these ribs, with joists framed between, he says, will be sufficient for the roadway." This method of construction, which has been brought to considerable perfection in Germany, America, and other places, will be understood from Fig. 307, in which D E F are three beams of the arch, consisting of logs of timber of small lengths, such as 10 or 12 feet, or such as can be found of a curvature suited to its place in the arch, without trimming it across the grain. Each beam is double, consisting of two logs, applied to each other side by side, *breaking joint*, as the workmen term it. They are kept together by wedges and keys, driven through them at short intervals, as at K, L, &c. The manner of joining and strongly binding the two side pieces of each beam is as follows:—the mortise *aicb* and *deio*, which is cut into each half-beam, is considerably larger on the outside than on the in, where the two mortises meet. Two keys, B B C C, are formed, each with a notch, *bcd* and *aeo*, on its side, which notch fits one end of the mortise. The inner side of the key is straight, but so formed that when both keys are in their places they have a space between them wider at one end than at the other. A wedge, A A, having the same taper as this space, is put in and driven hard, thus holding the two logs firmly together.

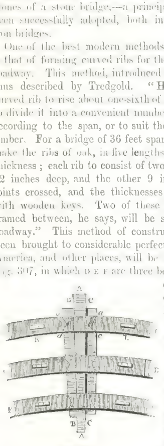


Fig. 307.

Colonel Douglass, in his work on "Military Bridges," notices the wooden arch, of 250 feet span, across the Portsmouth River, in North America. It was put together with wooden keys, on Price's method of construction, applied to a larger span, except that there is some difference in the form of the keys. The Colonel observes, that the arch is extremely flexible, and that diagonal braces would be an improvement in it. Also that if the three ribs had been placed close above one another, and firmly connected together, the bridge would have been much better adapted to resist any unequal load, because, in such case, they would have formed a solid beam, equal in depth to the sum of their depths. Tredgold remarks that it would have been still better to have made the same quantity of timber into two ribs, with cross ties and diagonal braces between them; that the method of connecting the parts by means of dovetail keys is objectionable, as the timber must be greatly weakened by such large mortises, and a very slight degree of shrinkage renders them useless; that it is still more objectionable as applied to the radial pieces, which would have been much better notched on in pairs, and bolted through.

There are many excellent wooden bridges in Switzerland. One of the most celebrated was that at Schaffhausen, constructed in 1757 by John Ulrich Grubenmann, a village carpenter of Teufen in Appenzel. It was composed of two arches, one 172 feet, the other 193 feet span, supported by abutments at the ends and by a stone pier in the middle, which remained when the stone bridge was swept away in 1754. In this bridge the oak beams which rested upon the masonry of the abutments and pier not having been properly seasoned, nor raised from the stone-work so as to allow the air to circulate around them, they rotted, and the frames began to settle. Grubenmann being dead, a carpenter of Schaffhausen named Spengler, undertook in 1783 to supply a remedy. He raised the whole bridge by means of screw-jacks upon scaffolding supported by piles, and replaced the decayed timbers by others of better quality. This was the only repair required by the bridge during the 42 years of its existence. It was burnt by the French army in 1799. The principle of its construction is shown in Fig. 311. Its chief defect was that all the principal supports were so dependent upon one another that a single part could not be removed without first supporting the whole bridge. This bridge in common with others constructed on the same principle bent considerably sideways.

Mr. Coxe says, that a man of the slightest weight felt this bridge almost tremble under him; yet waggons heavily laden passed over it without danger. It is frequently stated that the middle pier was not necessary as a support: the bridge however could not have borne its own weight without such assistance.

The general principles upon which timber bridges are constructed are very simple, and belong rather to CARPENTRY than to bridges. It will, however, be desirable to introduce a short notice of them here. If AB, Fig. 308, be a solid beam resting upon the supports A and B so as to form a roadway, it will have to support not only its own weight, but the planking and roadway and any heavy body passing over it. Now in order to strengthen such a beam without using a larger quantity of timber, we have only to make it deeper in the middle and thinner at the ends, as in Fig. 309, for a strain at c will have less effect in bending the beam than a similar strain in the middle. But if the weight be sufficient it will cause the beam to bend however it may be distributed, in which case the fibres at the upper side *d* will be compressed, and those on the lower side *e* extended. A line may however be drawn at the middle of the depth *acb*, where the fibres remain in their natural state, being neither extended nor compressed. But all the fibres between *c* and *d* are compressed, and all those between *c* and *e* are stretched; but not equally so, because the nearer a fibre is to the points *d* or *e* the more it is strained. Now as the middle part of the beam is very little strained compared with the upper and lower side, it is obvious that the same quantity of timber can be employed more effectually by using a deeper beam and cutting out the middle, as in Fig. 310. On examining the forces exerted by the parts of the beam it will be seen that the upper part *amdab* is wholly compressed in the direction of its length, and that the lower part *arcsb* is wholly extended in the direction of its length; and as timber offers the greatest resistance when strained in this direction, provided the joints are made secure, we are thus led to the kind of construction shown in Fig. 311, where the same pressures are evidently obtained as in the perforated beam, Fig. 310, the only difference being that in this case it is necessary to support the tie beam, or it would fail in large spans. The celebrated bridges of Schaffhausen, Zurich, Landsberg, and Wettingen, are constructed on this principle. In the bridge of Schaffhausen the timbers are disposed nearly as in Fig. 311: the continued tie AB retaining and being an abutment for the compressed beams: the frame requires only to be supported, and has no other thrust on the abutments of the bridge than a solid beam would have. Framed bridges such as that designed by Palladio, Fig. 306, may be referred to the same principle.

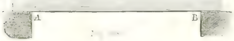


Fig. 308.

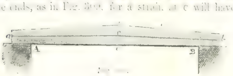
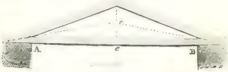


Fig. 309.



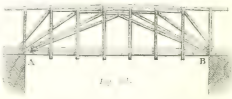


Fig. 311.

Advancing a step further it is easy to construct a bridge in which the tie is entirely removed, but in such cases the abutments must be capable of sustaining the thrust. Hence we get the kind of construction shown in Fig. 312. But as long pieces of timber require to be of a proportionate depth and breadth and cannot be easily procured, and as much of their strength is lost in scarfing, it is desirable to construct with short timbers. Hence we get such a combination as is shown in Fig. 313, which is a very common form. It was adopted by Palladio in a bridge across the Brenta. By dividing the span into shorter lengths than is here shown, little or no advantage is gained, because the angles of junction become more obtuse or open, and the strain in the direction of the pieces is much increased. Although such a bridge might bear a constant load, a load moving over it would soon derange it, because the strength of such a system to resist a variable load must depend wholly on the strength of the joinings, which cannot be made very strong. Bridges on this principle have, however, often been executed, as in Fig. 314, which shows the method adopted for the

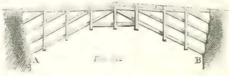


Fig. 312.

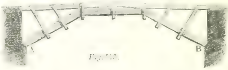


Fig. 313.

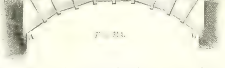


Fig. 314.

arches of the bridge over the Thames at Kingston: the span is 15 feet. Combinations of this kind naturally lead to the continued curved rib, which possesses advantages not found in a series of beams merely abutting end to end; for when the rib is built of short lengths with the joints crossed and the different thicknesses firmly bolted together, it becomes as one solid beam. If the straining force be applied at D, Fig. 315, it must be sufficient to fracture the

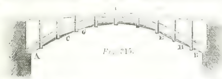


Fig. 315.

rib at C, D and E; therefore when the strength of the rib is capable of sustaining the strains at C, D and E, and the curve is a proper curve of equilibrium to the constant load, this combination is both secure and simple. The use of curved ribs of this kind was known at a very early period, and it has been further improved by bending the pieces that form the ribs. Many considerable structures on this principle have been erected, among which may be mentioned the bridge near Bamberg over the Regnitz, designed by Wiebeking, and built in 1809. Cast-iron bridges are constructed on nearly the same principle, as in Southwark Bridge, designed by Mr. Rennie, consisting of three arches, the span of the centre arch being 236 feet.

As a bridge with a curved rib and of considerable span yields at D, C and E, Fig. 315, when the load is applied at the middle, the strength must be increased by increasing the depth of the rib. This leads to the construction of a framed rib, Fig. 316. But in such case the two curved ribs must be continuous, and put together so as to resist either extension or compression: for when a load is placed at D, the lower rib will be extended to d and compressed at C and E; while the upper one will be compressed at D and extended at c and e; a weight applied at any other point would produce a similar effect. In bridges of large span framed ribs greatly add to stability. The framed voussoirs by Palladio, Fig. 306, resemble this kind of construction, but they are better adapted for iron bridges, where the parts cannot be very firmly united, in consequence of the expansion and contraction of the material according to variations in temperature; but in timber, where nothing is to be feared from this cause, it is, as Tredgold well remarks, losing one of the greatest advantages of the material to interrupt the connexion of the parts: besides, many joints should be avoided, on account of the difficulty of making them fit so as to bring every part alike into action, and also of the difficulty of preventing decay at the joinings.

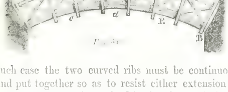


Fig. 316.

In cases where it is difficult to form abutments and it is desirable to keep the roadway as low as possible, Tredgold recommends such a construction as is shown in Fig. 317. Where the width of the bridge is considerable a rib may rise in the middle of the width so as to divide the roadway into two parts, or a double rib with a footway between. As cross ties will be required at the top, the middle parts may be covered with a roof to protect them. A continued coping $a\,a\,a'\,a'$ might be put over each truss, which would improve the appearance and protect the framing.

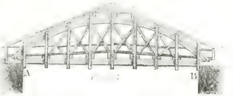


Fig. 317.

By the application of some of the simple combinations thus noticed, the carpenter will be able to span any opening of moderate dimensions.

Wiebeking states that a rise of 1 in 24 is a convenient ascent for a bridge; that in timber bridges the settlement is generally about 1 part in 72; that is, if a timber bridge of 144 feet span rise one foot in the middle when first framed, it will settle so as to become nearly horizontal; so that when it is intended for the bridge to have an ascent of 1 in 24 when finished, it must be framed so as to have a rise of 1 in 18; for $\frac{1}{18} = \frac{1}{24} + \frac{1}{72}$.

SECTION V.—SUSPENSION BRIDGES.

A suspension bridge derives its chief value from the fact that it is independent of the bed of the river which it crosses. Hence it can be thrown across an opening where it is impossible, either from the rapidity of the current or from the altitude of the banks, to erect centering for a stone bridge. It can also be built with ease and expedition; and as it requires only a small amount of materials, it is economical. There is also an elegant lightness about a suspension bridge; it is however on this account much slighter than stone or iron bridges, and there is probably no suspension bridge that would bear permanently the load that is passing every hour over London Bridge. "A bridge destined to be a great and perpetual thoroughfare, exposed not only to be frequently quite filled with people, and to the passage of troops, but also to the rapid motion of great numbers of heavy vehicles; in short, a bridge in a busy part of a great city, ought not to be on the suspension principle. For if it were made no stronger than our strongest suspension bridges, it would not possess sufficient stability. If on the other hand the strength were increased to a sufficient extent to enable it to bear safely its constant work, the weight, the difficulty of getting up the chains, and the increase in the masonry part, would so raise the expense, that it is doubtful how far it could be brought under that of a stone or cast-iron bridge. Add to which, a suspension bridge would never equal in stability a common arch bridge, because it is subject to vibrations, the law of which is not sufficiently known to calculate their precise results in practice, but which certainly are more dangerous in a heavy bridge than in a light one. The object therefore in building a suspension bridge, is either to make it so light that its own vibration shall not hurt it; or if, as in nine cases out of ten, that cannot be done, then to make it so heavy and stiff, in proportion to the load it will have to carry, that the load shall not cause it to vibrate much. This, for a bridge liable to be constantly loaded with as much as it could contain, would be impracticable."[1] For large openings where the traffic is small, suspension bridges are well adapted, because they can be carried to almost any span and any height, for a comparatively moderate expense. They are also well fitted for military bridges; the chains, or cables, the platform and even timbers being ready prepared to frame suspension piers, might be carried more conveniently than a pontoon bridge, and could be rigged up for use in a short time. They are also well adapted for crossing chasms in mountainous countries; and on a great military pass, a bridge of this kind would give the inhabitants greater command over it: for by knocking out a few connecting bolts, a whole bridge might be dismantled very rapidly without being destroyed. For piers or jetties on the sea-coast they are well adapted, from the openness of their construction. "If the suspension towers are founded on piles, and themselves made of strong but open framework, and if the chains and platform are properly combined to get as much stiffness with as little weight as possible, so that they may resist vibration, without being so heavy as to be endangered by the vibration they cannot resist, a suspension pier may be buried in the waves without being hurt."

The bridges of ropes, &c. mentioned at the beginning of this article, are true suspension bridges in their rudest form. They are very numerous in various parts of the world. In China, where the germ of nearly every thing connected with the Useful Arts is found, suspension bridges are formed of five parallel chains with links one foot in diameter, on which a loose bamboo flooring is laid. Another form is described as consisting of two parallel chains 4 feet apart, suspended over stone piers about 8 feet high on each bank. The ends of the chains pass back from thence, turn obliquely, and are bedded in the rock, each being fastened round a large stone, which is kept down by a mass of smaller stones laid upon it. A plank about 8 inches wide, extending across the river, is suspended from the chains by bands made of roots, of such length that the path is 4 feet below the chains in the middle of the length of the bridge. The suspending bands are renewed every year, and the planks are loose, so that any part can be repaired separately. The length of one of these bridges is described as being 59 feet. It is only used for foot-passengers; but it is a proper suspension bridge, with a horizontal platform suspended from the main chains.

Bridges of rope or cordage are described in works on Military Engineering as early as the year 1631, and perhaps earlier, but there does not seem to be any account of the existence of iron suspension bridges in Europe before the middle of the last century. About the year 1741, the first European chain-bridge was built in England across the Tees, two miles above Middleton, chiefly for the use of the miners of that district. The length was 70 feet, the breadth rather more than 2 feet, and the height above the water 60 feet. It appears to have been a very rude work, not superior to the Chinese chain-bridges. It attracted no attention at the time, nor does the construction of suspension bridges appear to have occupied the attention of English engineers until 1814. In America however iron suspension bridges were erected as early as 1796, by Mr. Finlay, who, in 1801, took out a patent for their construction. In 1811, eight bridges had been built on Finlay's plan.

In 1814, a plan was advanced by Mr. Dumbell of Warrington, for making a direct road from Runcorn in Cheshire, across the Mersey to Liverpool. The scheme included a bridge instead of a ferry across Runcorn-gap, and it was suggested to stretch across the river a web of metallic rings. From the nature of the navigation, it was necessary that any bridge to be constructed should consist of not more than three openings, the centre one of 1,000 feet, and the other two of 500 feet each, with a height of at least 70 feet under the bridge above high water. These conditions being submitted to Telford, he proposed an iron suspension bridge to consist of 16 iron cables, each formed of 36 square half inch iron bars, and of the segments of cylinders proper for forming them into one immense cylindrical iron cable, which was to be nearly half a mile long, including the fixings on shore, and about $1\frac{1}{4}$ inches diameter. The half-inch bars as well as the four segments were to be welded together into so many lines of bars, and laid in a bundle together, secured by bucklings every 5 feet, and wrapped in flannel saturated with a composition of rosin and beeswax, to preserve them from the weather. They were further to be bound together with wire of about $\frac{1}{10}$th inch diameter. The roadways were to be suspended from 16 of these cables, and to consist of two carriage ways and one central footpath. The main suspension piers of the middle opening were to be about 110 feet high, and the deflection of the cables in the middle $\frac{1}{20}$th of the opening or 50 feet.

At the time this bridge was proposed, there was but little experience on the construction of suspension bridges; and in order to obtain data for proportioning the strength of the parts, Telford undertook a course of experiments in 1814 upon the tenacity of malleable iron. "The inquiry was commenced by proving what force would tear asunder lengthways pieces of iron from $1\frac{1}{2}$ inch to $\frac{1}{20}$ inch in diameter. The experiments upon the first or larger diameters were performed with great accuracy, with an excellent hydrostatic machine, constructed by Mr. Fuller, at Mr. Brunton's

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(1) "A Memoir on Suspension Bridges," &c. by Charles Stewart Drewry. London, 1832.

patent chain-cable manufactory, Commercial Road, London: those upon the smaller diameters were made by weights attached perpendicularly, and sundry times repeated. Having ascertained their powers when suspended perpendicularly, I next made experiments upon different diameters from $\frac{1}{10}$ to $\frac{1}{20}$ of an inch, drawn horizontally and with different degrees of curvature: all these were done between points 900, 225, 140, $131\frac{1}{2}$ feet apart, and repeated sundry times upon the different distances and diameters. The number of experiments in all amounts to above 200.

"In the experiments made upon $\frac{1}{10}$ inch and under, the wire was drawn over pulleys; sometimes both ends were fixed, and sometimes one end only, the other having weights attached perpendicularly, to show their effects when compared with those loaded upon the curved part of the wire: these last were disposed at the $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ divisions of the distance over which it was stretched. Having completed these experiments, I next proved what force by a blow would break the wire when stretched nearly horizontal, and at different curvatures, which was done by dropping weights from a given height. The several wires upon which these experiments were made were weighed, and the weight of 100 feet in length of each noted.

"The results of these experiments were, that a bar of good malleable charcoal iron one inch square, will suspend 27 tons, and that an iron wire $\frac{1}{10}$ inch diameter, (100 feet in length, weighing 3 lbs. 3 oz.) will suspend 700 lbs.; and that the latter with a curvature or versed sine of $\frac{1}{50}$th part of the chord line, will support $\frac{1}{10}$th part of the weight suspended perpendicularly, when disposed equally at $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ of its length; and with a curvature of $\frac{1}{20}$th of the chord, it will bear $\frac{1}{3}$d of the aforesaid perpendicular weight, disposed in a similar way. Experiments upon the other diameters correspond sufficiently, and it was found that increasing the distance only varied the effect by the difference of the weight of metal contained in the wire employed.

"A wire $\frac{1}{10}$ inch in diameter, drawn very tight between points $32\frac{1}{2}$ feet apart, resisted the impulse of a 20 pound weight falling from a height of $7\frac{3}{4}$ feet. Several other experiments were tried with lesser weights upon this and smaller wires.

"From these experiments I had reason to be satisfied that English iron made with wood charcoal, had sufficient tenacity to bear itself, and a portion to spare equal to the purposes of a bridge across an opening of 1,000 feet, and therefore considered myself justified in proceeding to form designs."

The project for the Runcorn bridge was not carried out on account of the great expense of the undertaking; but it served to direct the attention of engineers to the subject, and may thus be regarded as the origin of the great extension that has since been given to the suspension mode of bridge-building. Between the time here referred to, and the erection of the Menai Suspension Bridge, several small suspension bridges had been erected in Great Britain. The first was built in 1816, by Mr. Lees at Galashiel, across Gala Water, to establish a communication between different parts of his manufactory. It was made of slender wires: the span was 111 feet, and the cost about 40*l*. Another bridge of iron wires was built in 1817 across the Tweed at King's Meadows. It is 110 feet long, and 4 feet wide. It was constructed by Messrs. Redpath and Brown, of Edinburgh, and cost about 160*l*. It is supported by two hollow cast-iron columns 9 feet high, 8 inches diameter, and $\frac{3}{4}$ inch thick in the metal, set on the opposite banks of the river 4 feet apart: in each column is placed a wrought-iron bar 10 feet high, $2\frac{1}{2}$ inches square; and the suspending wires are attached each separately to these bars by screw-bolts 1 inch diameter. The lower ends of the cast-iron columns stand on a framed wood foundation. The roadway is formed of wrought-iron frames, to which deal planks $1\frac{1}{2}$ inch thick are bolted. The side railing is of wrought-iron rods: the suspending wires are about $\frac{3}{10}$ths of an inch diameter, and are not arranged in a catenary, but one end of each is fastened to its supporting bar, and the other end is fastened to a part of the roadway, so that the wires are a set of inclined lines forming different angles with the vertical supporting bars, Fig. 318. When the wires are drawn tight by the screw-bolts the roadway is said to have very little motion. The strength of this bridge was tried shortly after its erection, by filling it entirely with a crowd of people, and it received no injury.

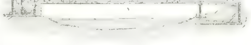

Fig. 318.

The system of inclined wires was adopted in a bridge built in 1817, at Dryburgh Abbey, across the Tweed, by Messrs. Smith. It was 260 feet span, and 4 feet wide. It was observed that the bridge had a very sensible vibration when crossed by any person, and the motion of the chains appeared to be easily accelerated. In 1818, six months after the completion of the bridge, a violent gale of wind caused so great a vibration of the chains that the longest chains broke, the platform was carried away, and the whole bridge destroyed. The vertical motion of the roadway was said to be, just before breaking, as great as the horizontal motion, and sufficiently violent to have thrown a person off the bridge.

"The defect of this plan of supporting a suspended roadway by inclined chains, fastened at the ends to the platform, is, that the chains, being of different lengths and inclinations, form different curves, and are exposed to very different degrees of tension; the long ones being the most strained, and the shortest the least. In a bridge of large span, and made with chains of any considerable weight, it would be almost impracticable to strain the inclined chains (especially the long ones) quite, or even nearly, tight; for if they were done, the tension to which they would be exposed would so far absorb their strength as to leave them little power of carrying any load beyond their own weight. On the other hand, by leaving them slack enough not to impair their strength, the difference of curvature and tension of the several chains, and their want of connexion and uniformity of action, cause the vibration to which they are exposed, from gusts of wind or the motion of carriages, to act unequally on the several chains; and the vibration is likely to be violent in proportion to the slackness of the chains. These reasons have probably led to the abandonment of this system for large suspension bridges. . . . In suspension bridges of large dimensions, and consequently of great weight, the force that the suspended mass will acquire by being put in motion increases rapidly. Hence, it is an object to make it resist motion, and especially to make every part bear its fair share of strain. It is a common doctrine that lightness is the peculiar excellence of a suspension bridge; but that is a principle which must be acted upon with discretion, and not taken generally; for a bridge may be from its size just so heavy that, by being put in motion, it will acquire great momentum, and just so light and slight that it will be unable to resist the effects of its own vibration. Therefore, when it becomes necessary to make the chains of a bridge so heavy that vibration would be dangerous, it is advisable boldly to increase their weight, rather than attempt to diminish it, and to bind and connect the several chains and the roadway firmly together, in order that there may be sufficient mass and stiffness in the bridge to resist motion, rather than yield to it readily."—*Drewry*.

Mr. Robert Stevenson, in a paper on suspension bridges, inserted in the 5th Vol. of Jameson's Edinburgh New Philosophical Journal, says:—"The effect we have to provide against in bridges of suspension is not merely what is technically termed *dead weight*. A more powerful agent exists in the sudden impulses or jerking motion of the load, which we have partly noticed in the description of the Dryburgh bridge. The greatest trial, for example, which the timber bridge at Montrose, about 500 feet in extent, has been considered to withstand is the passing of a regiment of foot, marching in regular time. A troop of cavalry, on the contrary, does not produce corresponding effects, owing to the irregular step of the horses. The same observations apply to a crowd of persons walking promiscuously, or a drove of cattle, which counteract the undulating and rocking motion observed on some occasions at the bridge of Montrose, when infantry has been passing along it. Hence, also, the effects of gusts of wind, often and violently repeated, which destroy the equilibrium of the parts of a bridge of suspension; and the importance of having the whole roadway and side-rails framed in the strongest possible manner."

The destruction of the Dryburgh bridge created a great sensation of regret throughout all parts of the country. Its utility when compared with a troublesome ferry, even in the short experience of six months. had given it such a decided preference to the boat, that the Earl of Buchan, the owner, ordered it to be restored. This was accordingly done, after a better design, for the additional sum of 220*l*., (somewhat less than 500*l*. having been paid for the original structure, which the contractors agreed to uphold against all accidents only during the period of its erection,) and, in less than three months, it was again opened to the public. The bridge was reconstructed on the catenarian principle, the roadway being suspended by perpendicular rods of iron from main or catenarian chains. The chief mechanical alterations upon the former plan consisted in welding both eyes or ends of the links, instead of having one of them simply turned round, and fixed with a collar. The roadway was also strengthened by a strongly trussed wooden rail, which also answers the purpose of a parapet, on each side of the bridge, the good effects of which were particularly exemplified while the bridge was building. A high wind having occurred before the side-rails were erected, one end of the platform was lifted above the level of the roadway, and the undulating motion produced on this occasion is described as resembling a wave of the sea; an effect which pervaded the whole extent of the bridge, and went off with a jerking motion at the further end. But after the side-rails were attached, this vertical motion was checked, and afterwards greatly reduced. There were also added gyes or mooring-chains, consisting of rods of iron fixed to stakes in the opposite banks of the river, and attached to the beams of the roadway. These diagonal moorings are said to have some effect in lessening the motion of the bridge in high winds.

The plan proposed for Runcorn Bridge was, as already stated, to suspend the platform from iron cables, made of small bars, welded together at their ends, and bound up together, so as to form a long flexible bar or cable. That plan has not been adopted, the usual system being to make the chains of straight wrought-iron rods or bars, from 5 to 15 feet long, with either welded eyes or holes drilled out at their ends, by which they are connected together in pairs by short links and bolt-pins. This system was introduced by Captain Samuel Brown, R.N., who, in 1817, took out a patent for his invention. His reasons for preferring this mode of making the main chains to making them of links, like chain cables, or of small wires, were, that link chains are weaker in proportion to their weight than bars, a portion of the strength of the iron being lost in bending it into the form of a link; and small wires are inexpedient for large bridges, on account of the number of parts and complication of joinings required, and also on account of the great surface they expose to damp, and their consequent liability to destruction. The Union Bridge across the Tweed, five miles above Berwick, was the first large bar-chain bridge completed in this country. It was begun in August, 1819, and opened in July, 1820, just after the commencement of the Menai Bridge.

The straits of Menai, which separate the island of

Anglesea from Caernarvonshire, had long formed a troublesome obstruction upon the great road from London to Dublin by Holyhead. The connexion between the two shores was maintained by six ferries, the most important of which was th[illegible] north of certain rocks in the current, called the *Swellies*, named *Bangor Ferry*, from its proximity to the city of Bangor. The idea had long been entertained of superseding the ferry by a permanent roadway; but no plan had been entertained until after the union of Ireland with England, when the increased intercourse between the two countries led the Government, in 1801, to direct Mr. Rennie to survey the strait, and prepare a plan and estimate for a bridge. Four designs were accordingly prepared for a cast-iron structure; and, while these were under consideration, a violent opposition was made to the erection of a bridge, by interested parties, and it was affirmed that the effect of a bridge would be to destroy the navigation of the strait. A parliamentary committee, however, reported that the bridge was desirable, and in no way likely to prove injurious; and they advised the immediate construction of the proposed bridge, with three cast-iron arches, over the Swellies. Upon this, the Lords of the Treasury directed Mr. Telford to survey the Holyhead Road, and to consider the best mode of passing the Menai Strait. This was done; and in April, 1811, Telford proposed a cast-iron bridge, of one arch, 500 feet span, 100 feet clear in height, at high spring tides, and 40 feet broad. As it was nearly impossible to construct the centering of the arch from below, on account of the nature of the bottom of the channel, and the great rise and rapidity of the tides, Telford proposed to suspend the centering from above.

This plan was strongly recommended for adoption by the parliamentary committee, in their report, in May, 1811; but the difficulties in which the country had been involved by the long protracted war abroad interfered with improvements at home, and nothing was done in the matter until 1818. In the interval, however, public attention had been drawn to the subject of suspension-bridges; and the improvements of the Holyhead Road being in active progress, in pursuance of an Act passed in 1815, under Telford's direction, he was ordered, in 1818, by Government, to give his opinion whether a suspension-bridge was practicable over the Menai Straits, and if so, to prepare a design. Telford accordingly surveyed the localities, and proposed a suspension-bridge at Ynys y Moch. Evidence was taken by the committee, at considerable length, on the plan proposed, and the opinions of engineers being favourable, a report was made, and 20,000*l.* voted by Parliament to enable the commissioners to commence operations; but, in consequence of the opposition of interested parties, the building of the bridge was delayed until July, 1819, when an Act was passed, giving proper powers for carrying on the erection of the bridge.

We come now to describe the finished structure.

	Feet.	Inches.
The distance apart of the centres of the summits of the main pyramids is	579	[illegible]
The deflection of the chains in the middle	43	0
The clear height of the roadway above high water	102	0
Breadth of the platform	28	0

It is divided into two carriage-ways, one on each side of the bridge, 12 feet wide, and a central footpath, 4 feet wide.

The piers of suspension are pyramids, built of grey Anglesea marble. The Anglesea main pier stands on the rock Ynys y Moch, which was levelled by blasting to form a foundation, and rises to about the level of high water. On the Caernarvon side the foundation of the pier is sunk 7 feet below the surface of the beach, and is also firm rock. The main piers are 100 feet high, from the level of high water line up to the level of the roadway, and their summits are 53 feet above the roadway. The slope of the piers below the roadway is [illegible]; their extreme breadth at the base 70 feet, and at the summit 15 feet. Their thickness at the base is 50 feet, at the level of the roadway 29 feet, and at the summit 11 feet. They are not built solid all the way up; but, in each, four hollow squares, about 9½ feet square, were left, commencing above high water mark, and running up to within about 4 feet of the level of the roadway. Through each main pier two arched openings are formed for the passage of carriages, 9 feet wide, and 15 feet high to the springing of the arches, the wall between them being a little more than 6 feet thick. The masonry above the openings is tied together by iron dowels, 1 inch diameter, and 12 inches long, put through holes drilled through each stone of every course. To prevent the walls of the arches for the carriage-roads being pressed out by the weight of the superincumbent part of the pyramid, 6 wrought-iron tie-bolts, 4 inches wide by 2 inches thick, are laid in the masonry at the springing of the arches, with dovetail heads at each end, let into corresponding sockets in cast-iron plates bedded in the masonry. The main piers are connected with the shores by a series of arches, three on the Caernarvon side, and four on the Anglesea side. The height of each of the small piers, from high-water line to the springing of the arch, is 65 feet, and the span of each arch 52½ feet. A square chamber is left in each, filled up with rubble.

The main chains are on Capt. Brown's plan of straight bars, A, Fig. 319, united by coupling bolts. The main chains are 16 in number, each containing a series of links composed of 5 wrought-iron bars, 9 feet 1¾ inch long, 3¼ inches broad, and 1 inch thick. They are disposed, four chains one under the other, on each side of the central footpath, and four at each outside of the platform. So that there are in all 80 bars in the main chains, and their united section is 80 + 3¼ = 260 square inches of iron. The bars are united by coupling plates, B, Fig. 319, 16 inches long, 7½ inches broad, by

1 inch thick, and screw-bolts, c, Fig. 319, 3 inches diameter, each bolt weighing 56 lbs. The main

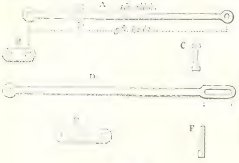

Fig. 319.

chains are carried through tunnels cut through the solid rock of which the shores are composed, and the extreme ends are fastened by strong holding bolts in chambers made at the ends of the tunnels. The holding bolts are 9 feet long and 6 inches diameter, and rest in sockets in cast-iron plates 6 inches thick. There are 12 holding bolts at each end of the bridge, viz. 4 for the two middle sets of chains, and 4 for each of the outer ones. The length of each bolt between its bearings against the rock is 18 inches. There are 3 tunnels for the chains, about 5 feet square, at each end of the bridge, viz. one for the two central sets of chains, and one for each of the outer ones. The bars of the chains in the tunnels are much stronger than the other bars, under the idea that in the tunnels they would be more exposed to rust, and less accessible for painting or varnishing them. The back stays are tied down, by vertical rods, to small cast-iron plates laid in the masonry of the arches between the main piers and the shores, to prevent their undulation.

Thus the main chains are fixed firmly at their extremities into the rock, and are also held down between the main pyramids and the shores: but over the pyramids they lie loosely upon cast-iron saddles, laid upon horizontal rollers or trucks, 3 feet 8 inches long and 8 inches diameter, that lie in grooves or channels formed in a cast-iron platform upon the summit of each main pier. The saddles can thus move backwards and forwards a few inches in the direction of the length of the chain, and hence expansion and contraction of the chains produce no other effect than to move the saddles on which they lie, just as much as they lengthen or shorten, and to raise or depress the suspended roadway a little, instead of producing an injurious strain on the materials. The rollers on which the saddles rest, are kept equidistant by their necks or projecting ends being received in brasses held between wrought-iron plates screwed together, so that no one roller can move alone; but there is sufficient space in the grooves in which the rollers are placed, for all of them to move as much as $4\frac{1}{2}$ inches.

The chains are tied together across the breadth of the bridge by transverse ties, which are cast-iron tubes placed between each pair of chains, with wrought-iron screw bolts put through them, and passing through the chains. The bolts serve to draw the chains together by their nuts, and the cast-iron tubes keep the chains a proper distance apart. There are 8 of these transverse ties in the length of the bridge. The chains are further tied together by a diagonal wrought-iron lacing between each pair of transverse ties. This mode of binding the chains was adopted in consequence of the effect perceived on them from the action of gusts of wind, while the bridge was in progress.

In the length of the chains there are 4 sets of adjusting links to every line of chains, viz. 2 in the opening between the piers, and 1 between each pier and the shore. The object was, to give the means of adjusting the chains to their proper length, in case there should be any inequality in the lengths of the bars. Fig. 320 is a perspective view of one of the adjusting links, and D E, Fig. 319, is a side view of the same. At one end of each of the bars a, a long hole is made instead of a round eye, and the corresponding end of the connecting plate b has also a long hole in it. The bar and connecting plate are connected by two semicircular pins, 1 and 2, one bearing against the ends of the bars a, and the other against the ends of the connecting plates b, Fig. 320, and E, Fig. 319. and the space between them is filled up with iron wedges, 3,3. If any one of these iron wedges be taken out, the ends of the bars a can be drawn away a little from the ends of the connecting plates b, and so the chain will be lengthened; or by driving in more wedges, the two semicircular pins, 1, 2, are separated further and the chains shortened. The bars c are connected to the other ends of the connecting plates b, by screw bolts, like the other bars of the chain. The whole distance that each adjusting link can be lengthened is $9\frac{1}{2}$ inches: so that as the chains can be lengthened 19 inches between the pyramids, and $9\frac{1}{2}$ more between each pyramid and the shore, allowance is made for 38 inches in all.

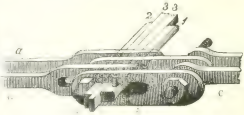

Fig. 320.

The roadway is laid upon wrought-iron cross-bars or roadway bearers, suspended from the ends of the vertical suspending rods. The bearing bars are $3\frac{1}{2}$ inches deep, and $\frac{1}{2}$ inch thick, placed 1 inch asunder, and the space between them is filled up with a piece of deal. They are trussed with bent ties and struts underneath. The roadway consists of two thicknesses of fir plank, the lower one of 3 inches, the upper one of 2 inches, laid parallel with the length of the bridge, upon the iron cross bearers. The lower course is bolted to the wood that is riveted between the iron roadway bars, and is covered with patent felt saturated with boiled tar; the second course of planking is spiked through to the lower course. In the middle of each carriage-way a third course of planking, 2 inches thick, is spiked through to the second, through an intermediate layer of felting; and an oak guard is bolted on each side of the carriage-way through the two lower courses of planking. Also to stiffen the roadway, an oak plank is bolted to the underside of it between each of the cross bearers.

All the suspended iron-work of the bridge, before being put up, was proved by actual strain in a proving machine, at the rate of 11 tons strain per square inch.[1]

The chain-work was put up in the following manner. The chains were first put together in the tunnels, working up from the fastenings to the mouths of the tunnels, by bringing down one link of each chain at a time, and bolting it to the one previously brought down. The chains were then put together from the mouths of the tunnels up to the main piers, upon a scaffolding erected on the masonry between the pier and the shore, with the proper inclination for the back stays. The chains were then continued over the Caernarvon pier, and allowed to hang loosely down to the level of high water. This was done by suspending a cradle large enough for two men to sit in, from a crane-arm set up on the top of the pyramid. The cradle was suspended by tackle, so that the men could slack it down or haul it up, to raise or lower themselves at pleasure. The links of the chain that were to be joined on to the ends of the hanging chain, were brought in succession along the road to the front, or the sea face of the pyramid, through the arched roadway opening. The link was then taken up by tackle from a pair of shears placed on the top of the pyramid, and lifted up to the height of the link it was to be fixed to, where the men in the cradle got hold of it and brought the two links together, and put the coupling bolt through them.

On the Anglesea side of the street the chains were carried just over their saddles on the top of the pier, and their ends were retained by tackle made fast to them, and descending thence to capstans on the shore. The remaining piece or length of chain which was to unite the two ends of the chains brought up from each shore, was laid on a raft, 400 feet long, and 6 feet wide. One end of that piece of chain was first attached to the end that hung down to the water from the Caernarvon pier, and then the raft was floated across to the Anglesea pier, and the loose end of the chain upon it was fastened to the tackle which hung down from that pier. The tackle was then hauled up by the capstans fixed on the shore, and the chain was gradually raised off the raft until the end of it was brought in contact with the end of chain that hung over the top of the pier. The two loose ends were then bolted together and the operation completed. The first chain was thus raised and fixed on the 26th May, 1825, in 1 hour 35 minutes. The other 15 chains were successively got up in the same way at subsequent periods, the second chain being got up on the 28th April, and the fifteenth on the 28th June.

The hoisting of the first chain is thus described by Mr. Provis, the resident engineer:—"Whilst these operations were going on below, [*i.e.* securing the two ends of the chain at the Caernarvon pier,] the two capstans were manned by about 150 labourers, and everything above put in readiness. The word "go along" was then given, when a band of fifers struck up a lively tune, and the capstans were instantly in motion. As soon as each main fall or leading rope had coiled from the bottom to the top of its respective capstan barrel, the capstans were stopped, the clams screwed hard down upon the main falls, and held there till the ropes were shipped (or fleeted) down, from the tops to the bottoms of the barrels. The clams were then unscrewed, a fresh tune struck up, and the men resumed their task with renewed spirit. At first they had little to do but haul up the slack of the tackles, but when these were tightened, and the weight of the chain, which was gradually rising, began to be felt, the race which they had hitherto run at the capstans was reduced to a steady trot. Before the chain was lifted quite off the raft, the direction of the tide had changed, and the anchors being all on what was the up-stream side of the raft when it was moored, were of no use now in resisting the force of the contrary current. The raft was consequently forced from under the middle of the chain, which swung easily off into the water. Till this time scarcely a word had been heard but the directions to 'hold on' or 'go along,' but as soon as the chain was fairly suspended above the surface of the water, we were greeted with a hearty cheer from the surrounding crowd. As soon as the raft had drifted from under the chain, the anchors were weighed; the ropes which held to the ringbolts at the Caernarvonshire pier were slacked to give the raft sufficient play, and in a few minutes it was floated to its berth on the shore and secured in readiness for another chain." Many of the strangers assembled to witness the operation were eager to relieve the workmen at the capstans, "anxious to have it in their power to say they had helped to put up the first chain of the Menai Bridge." The whole operation was conducted in the most satisfactory manner. "Every man was at his post and anxious to do all he could to ensure success. Not the slightest accident, nor even a single blunder, occurred from the time of casting off the raft till the chain was secured in its place. Mr. Telford now ascended the pyramid to satisfy himself that all was right; and there, surrounded by his assistants, the contractors and as many as could find a place to stand on, received the congratulations of many a friend to the Bridge. The hats on the pyramid were soon off, the signal was understood by all around, and three cheers loud and long closed the labour of the day. The ceremony was scarcely over when one of the workmen got astride the chain, and passed himself over it to the opposite side of the Strait. Another followed soon after and actually had the temerity to raise himself up and walk over 30 or 40 feet of the middle of the chain, though the slightest slip must have sent him to destruction; the chain being only 9 inches wide, and its height at that time above the surface of the water not less than 120 feet."[1]

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[1] The proving machine was similar to that used by Captain Brown. It consists of two rollers set up in bearings, one at each end of a long iron frame. On the axle of one of the rollers a strong lever projecting out horizontally is fixed; its end is connected, by a short vertical link, to the short end of a counter horizontal lever mounted on a fixed centre pin; the long end of this lever is loaded, the proportions of the levers being such, that a very moderate weight on the end of the counter lever, will exert great power to turn the roller round. A short vertical arm projects out below the circumference of the roller, to which a piece of chain is linked. One end of the bar to be proved, is fastened to the end of that chain, and the other end is linked to a chain attached to the opposite roller. This second roller is turned round by 2, 4 or 6 men, according to the size of the bar under proof, by means of a train of 3 wheels and 3 pinions, until the loaded roller is pulled or turned round enough to raise up its balance weight, which is the measure of the strain the bar is intended to undergo. In the machine used at Capt. Brown's manufactory, the proportions of the two levers were such as to multiply the effect of the balance weight 224 times, and the train of wheelwork was so proportioned, that two men at the handles could exert a force of 30 tons on the bar under proof.

It is related in the appendix to the Autobiography of Telford, (London, 1838,) that when the second chain had been got up, a labourer, after finishing his day's work, sat himself down quietly on the centre of the curved part of the upper suspension chain, with his feet resting on the one below it, and in that position actually went through the regular operation of making a pair of small shoes in the short space of 2 hours: he afterwards sold the shoes for a sovereign, and was led to suppose that they were purchased for public exhibition at the British Museum.

The hoisting tackle consisted of two ropes, each leading from a capstan fixed on the shore between 400 and 500 feet back from the pyramid, and there passed over two pulleys 14 inches diameter, fixed in a strong frame placed on the top of the pyramid. Hence the ropes passed through a block of four sheaves made fast to the end of the piece of chain on the raft. Hence the rope led up again through a three-sheaved block at the top of the pyramid, lashed to one of the chains of the back-stays, and lastly, through a single-sheaved block made fast to the end link of the chain hanging over the summit of the pyramid, to which the end brought up from the raft was to be attached. The barrels of the capstans were 1 foot 8 inches diameter; the axles about 4 inches diameter, worked by 8 spanners of 10 feet radius, and manned by about 150 men for the two.

The bridge was opened on the 30th January 1826, or $6\frac{1}{3}$ years after its commencement; several improvements and alterations were made during the summer months of 1826, in order to stiffen the chains and roadway. There is no perceptible transverse vibration of the roadway: the vertical undulation before the introduction of the transverse ties and diagonal lacing was about 18 inches, but afterwards it was not found to exceed 6 inches. The chains are scraped and painted once in 3 years. The longitudinal motion on the pyramids by expansion and contraction of the chains has been observed to the extent of 2 inches.

	Tons	Cwt.	qrs.	lbs.
The weight of the 16 main chains between the points of support, including connecting plates, screw pins, wedges, &c. is computed at . . .	391	5	0	16
The transverse ties	3	16	2	20
The weight of the suspending rods and platform, viz. roadway bars, planking, side-rails, iron-work, &c.	245	13	2	27
Making the total suspending weight	643	15	2	7

Whence the tension of the iron at each point of suspension is by the weight of the bridge itself, according to experiment,[3] 1.7 times 643 ,, 15 ,, 2 ,, 7 = 1,094.42 tons.

The entire section of the 80 bars is 80 × 3.25 = 260 square inches, which would bear without breaking 260 × 27 = 7,020 tons.

According to Telford's experiments, about half the breaking strain, or 3,513 tons, would produce permanent elongation; and if we take the standard of 9 tons per square inch, the chains will bear constantly without any risk 9 × 260 = 2,340 tons or 2,340 − 1,094.42 = 1,245.5 tons of strain produced by the weight of the bridge itself. Therefore it may be perpetually loaded without any injury with $\frac{1245.5}{1.7}$ or about $732\frac{1}{2}$ tons besides its own weight.

Such are the details of the Menai Suspension Bridge. Few works connected with the profession of a Civil Engineer have excited more interest, "for," as Mr. Provis remarks, "though the principle of its construction is old as the spider's web, the application on a scale of such magnitude, the durability of the materials of which the bridge is composed, and the scientific combination of its various parts, render it one of the noblest examples of British skill. As a public convenience too, it is of the highest importance; for instead of an uncertain ferry over an often tempestuous strait, at all times crossed with trouble and delay, and frequently at the risk of life, a commodious roadway has now been established between its shores, that can be passed at all times with safety and comfort."

The Conway Suspension Bridge was built to replace a ferry across the estuary between the town of Conway and the opposite shore that leads to Chester, and to connect by a safe and permanent road across that estuary the towns of Bangor and Chester. It was commenced in 1822, and completed in 1826, and differs but little in construction from that of the Menai Bridge. The chains, however, were put up in a different manner. A temporary rope bridge was made with the ropes used for the hoisting tackle at the Menai Bridge; and on that the chains were put together in the places intended for them; after which the ropes were slacked and the chains adjusted to their proper tension. The distance between the points of support is 327 feet, the deflection $22\frac{1}{3}$ feet, and the height of the under side of the roadway above high-water of spring tides is 15 feet.

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[1] An [illegible] By W. A. Provis, [illegible] London, [illegible]

(2) Before suspending the main chains experiments were made by Mr. Rhodes to find the tension required to draw them up to the required curvature. They were tried with a chain made of some of the vertical suspending rods 1 inch square, with a chord line of 570 feet, and deflections varying from 30 feet to 49 feet. He found the tension of the chain at 43 feet deflection, viz. the intended deflection of the chairs = 6,[illegible] lbs. The weight of the chain was 3,[illegible] lbs., hence the tension was 1.7 times the weight suspended

About the time when the Conway Bridge was begun, the Brighton Chain Pier was commenced by Captain Brown in October 1822, and was opened in November 1823. It runs out into the sea 1,014 feet from the face of the esplanade wall. The entire length of the bridge is 1,136 feet, in four openings, each of 255 feet span and 18 feet deflection. The extreme breadth of the platform is 13 feet, and the clear breadth 12 feet 8 inches. The suspension towers consist of pyramidal cast-iron frames, one on each side of the bridge, united by an arch at the top. They are 25 feet high, 10 feet apart, and weigh each about 15 tons. They stand on clumps of piles driven about 10 feet into the chalk rock that forms the bed of the sea, and rising 13 feet above high water. The clump of piles at the outer end or pier head is in the form of the letter T, and contains 150 perpendicular piles besides the diagonal piles, framed strongly together with walings and cross braces. On them a platform is laid 80 feet by 40, paved with a course of Purbeck granite. The three other clumps contain each 20 piles, besides the diagonal piles. The platform is supported by 4 chains on each side of the bridge, arranged two in breadth and two in depth. They are of wrought-iron round eyebolts about 2 inches in diameter, 10 feet long, and united by open coupling links and bolt-pins. They rest upon saddles on the upper part of the suspension towers. The chains on the land-side are carried over a suspension pier of masonry, and the back stays are carried through two tunnels in the cliff and properly secured. The back stays at the pier head are fastened to the diagonal piles. The platform is suspended from the main chains by vertical suspending rods 1 inch in diameter and 5 feet apart, viz. one at every coupling of the chains. At their upper ends they are formed with a cross or T head, Figs. 321, 322, which is supported by a cap resting upon the ends of the main chains and coupling links, one cap at every coupling. A square cavity or chamber is cast in the lower part of each of the caps, with an oblong slit or entrance, through which the T head of the vertical rod is put upwards, and being turned round in it across the slit, is borne up by the cap as shown in Fig. 322. The lower ends of the vertical rods spread out into forks, which clasp over and are fastened by cross pins to a longitudinal side bearer made of bars of flat iron, bolted together and extending from tower to tower. On the side bearers are laid cross joints $7\frac{1}{2}$ inches deep by $3\frac{1}{2}$ thick, and over these is laid a course of planking for the roadway. The platform is guarded and stiffened by an iron railing or parapet.

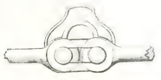

Fig. 321.

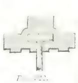

Fig. 322.

Considerable difficulty was experienced in driving the piles, on account of the hardness of the bed of the sea, and the storms which are common on that coast. The work, however, was completed, and the pier continued during many years to render its useful services. It withstood the shock of many a violent tempest; but at length, in November 1836, it yielded to a gale of wind. The roadway of the pier gave way half an hour after midday of the 29th, about which time Osler's anemometer recorded the pressure caused by the wind's force at Birmingham as equal to $11\frac{1}{2}$ pounds on the square foot. The barometer at Greenwich had sunk to 29.24; the wind's force there also being denoted by $11\frac{1}{2}$. There was a double motion in the pier, for both chains and roadway oscillated laterally, and undulated longitudinally; but the latter movement increased greatly, whilst the former diminished, just before the fracture took place.

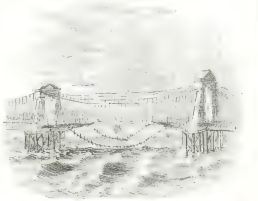

Fig. 323. [illegible] BRIGHTON CHAIN PIER, [illegible] THE 29TH NOV. 1836.

It was probably owing to this double motion that half the upper part of the roadway, and half the under part, were visible to the spectators at the same instant. As soon as the side-rails gave way, the undulations greatly increased, and almost immediately afterwards the roadway broke. It was remarked at the time that, had the side-railing been a trussed rail, the pier would probably have withstood the force of the storm. Fig. 323 is a sketch of the ruins of the pier after the accident.

The suspension bridge at Montrose was blown up by the hurricane of the 11th October, 1838. Colonel Pasley, who was sent to inspect the bridge, remarks, that "it was blown up from below; it being, like our English roofs, rather resting by its own weight than secured against hurricanes [illegible]. The [illegible]

Montrose had nothing to stiffen it laterally or in a vertical direction. Iron transverse bearers, suspended by the rods, had two tiers of planking over them, and a light railing on each side, like that of a common balcony. The suspension bridge at Hammersmith, on the contrary, has railing of strong iron posts, and the rest of wood, on each side; and two longitudinal sets of king-post trusses on each side of the carriage-way, and between it and the footpaths."

Mr. Rendell was employed by Government to repair the chain bridge at Montrose. The manner in which he proposed to truss the bridge, to prevent a recurrence of the same misfortune, is here shown. Fig. 324 is a longitudinal section of the trussed rail, which, it will be seen, passes below the bridge as well as above it; and Fig. 325 is a transverse section, showing cross-bracing at every 35 feet, below the roadway.

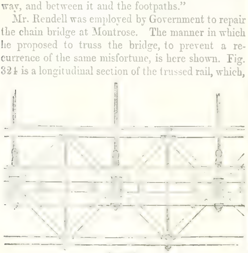

Fig. 324.

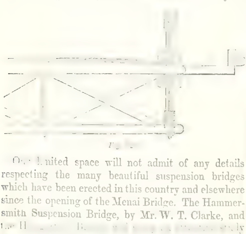

Fig. 325.

Our limited space will not admit of any details respecting the many beautiful suspension bridges which have been erected in this country and elsewhere since the opening of the Menai Bridge. The Hammersmith Suspension Bridge, by Mr. W. T. Clarke, and the H [illegible]ly on the part of those interested professionally in these subjects. The former is described in Mr. Drewry's work, together with a number of other bridges, either proposed or actually erected, up to the date of its publication, in 1832.

Some of the French engineers have preferred wire to bar-iron for suspension bridges. The reasons given by them for this preference are, that iron wire is stronger than bar-iron; that cables of wire can be put together more easily and rapidly than chains; that it is more easy to ascertain whether it be sound or not; and, that it is easier to get wire cables up into their places than bar-chains.

The facility of working wire, without heavy machinery, may render its use expedient in small structures; but it has many disadvantages for larger ones. First, as Mr. Drewry states, "although a single wire is stronger per square inch than a bar of iron, it is much to be doubted whether a cable made of wires is stronger than a bar-chain of equivalent dimensions, because of the inequality of tension in the several wires, which throws a greater share of strain on some than on others, and therefore reduces the effective length of the cable to that of a cable of less diameter. This inequality it is hardly possible to prevent, even if the wires are drawn, in making up the cables, to the same curvature that they are intended to have when in their places. Secondly, wires, exposing a greater surface than bars of equal section, are more quickly destroyed by oxidation. A coating of varnish, it is true, may somewhat preserve them; but bars may also be preserved by varnish and painting, and are still on that point superior to wire cables. Thirdly, wires are very apt to have kinks and bends in them, which cannot be got out without a very considerable strain: and when that has been done, it is difficult to ascertain whether the wire has not been permanently injured at that part. The long bends, also, that are formed frequently in wire can hardly be got rid of at all. . . . Lastly, although a small cable is very easily got up into its place, it is so, not because it is a cable, but because it is comparatively small and light."

In 1823, a wire bridge was erected over the double ditch of the fortifications at Geneva. The wires were of small size, laid together side by side, and bound up into small cables by wire wound spirally round them. It was erected under the direction of Colonel Dufour, an officer of engineers, at the cost of little more than 640*l*. The inner ditch is 109 feet wide, the outer one 75½ feet wide, and the embankment or counterguard between the two 82½ feet wide. The breadth of each opening is 131 feet clear between the piers, which are of masonry. The main cables pass over the piers in grooves formed in bed stones on the tops of the piers: the edges of the grooves are rounded off where the cables come on them, and are covered with a thin brass plate. The ends of the cables at the tower end are attached to vertical bars, 7½ feet long, and 1⅜ inch square, which descend close against the back of the pier; their lower ends are linked to horizontal bars laid on edge in the foundations of the piers. The back stays being thus carried down perpendicularly, this pier has to bear all the drag of the bridge to pull it over, and is made larger and stronger than the others in proportion. At the opposite end of the bridge, the cables are fastened to inclined bars. The cables are in several lengths, there being one long cable across each opening, and three short ones over each pier. By varying the different lengths of the short connecting cables that lie on the tops of the piers, the main cables are adjusted. The ends of the long cables are fastened to the short ones by wire links, Fig. 327; loops at the ends of the cables are made like the loop of a cord, by simply turning the wires back upon themselves, and then binding the

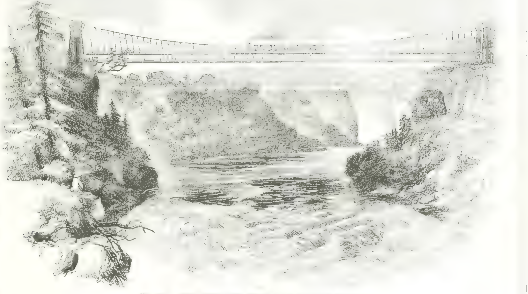

Fig. 326. WIRE SUSPENSION [illegible]

loose ends of the cable together by a wire wound tight round them at *a a*. The cables I and L are

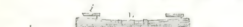

Fig. 327.

united by bolt-pins, made hollow, that they may be of large diameter without being heavy. Where the cables are looped round the ends of the iron bars for the back stays, *b*, Fig. 328, a small semicircular brass

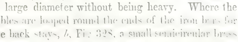

Fig. 328.

washer *a* is interposed, to prevent the wire being bent too abruptly.

The platform consists of cross joints suspended from the main cables by short vertical cables, each containing 12 wires. The upper ends are looped round the main cables, and the ends tied round by a wire, in the way described of the loops at the end of the cables; and the lower ends are simply looped round the ends of the cross joints, and also tied. The parapet is 3½ feet high, composed of small iron rods, with a top rail, and two other rails of flat iron. The parapet is inside the suspension wires, to guard them from injury. It is steadied by diagonal ties, about 25 feet from each end.

The load on the larger opening is thus calculated:—

160 persons	23,205 lbs.
Weight of bridge, platform, &c.	15,912
Chains, &c.	1,547
Chance load	221
	40,885 = 18¼ tons.

The angle of direction of the chains is 19°, and the tension for that angle is about 1.5 times the weight = 27⅜ tons. The ultimate strength of the cables is 111½ tons, and they might be safely loaded with one-third of that, or 37 tons, instead of 27⅜. The bridge vibrates very much from the great slackness and lightness of the construction. It is well adapted for its purpose, being intended only for foot passengers; but it would be dangerous to allow it to be completely loaded, or to allow more than 50 men to march over it in step.

The most remarkable wire suspension bridge in Europe, on account of its dimensions and height, is that of Freyburg, in Switzerland, commenced by M. Chaley, of Lyons, in the spring of 1832, and opened to the public on the 23d August, 1834. This bridge has a span, from pier to pier, of 870 feet, and is suspended at the height of 167 feet above the river which flows under it. It is thus 319 feet longer than the Menai Bridge, and 65 feet higher. "It is supported on 4 cables of iron wire, each containing 1,056 wires, the united strength of which is capable of supporting three times the weight which the bridge will ever be likely to bear, or three times the weight of two rows of waggons extending entirely across it. The cables enter the ground on each side obliquely for a considerable distance, and are then carried down vertical shafts cut in the rock, and filled with masonry, through which they pass, being attached at the extremity to enormous blocks of stone. The materials of which it is composed are almost exclusively Swiss. The iron came from Berne; the limestone masonry from the quarries of the Jura; the woodwork from the forests of Freyburg; the workmen were, with the exception of one man, natives, who had never seen such a bridge before. It was completed at an expense of about 25,000*l.* sterling, and, in 1834, was subjected to various severe trials, to prove its strength. First, 15 pieces of artillery, drawn by 50 horses, and accompanied by 300 people, passed over it at one time, and were collected in as close a body as possible, first on the centre and then at the two extremities, to try the effect of their concentrated weight. A depression of 39⅓ inches was thus produced in the part most weighted upon; but no sensible oscillation was occasioned. A few days after, the bridge was opened by the bishop and the authorities of the town, accompanied by about 2,000 persons, who passed over it twice in procession, preceded by a military band, and keeping step. On this occasion a slight horizontal vibration was produced; but it is very improbable that the bridge, in its ordinary service, will ever receive such a multitude at once. The passage of 2 or 3 heavy carriages or carts across it causes only the slightest perceptible oscillation; and nothing is more extraordinary in this beautiful structure than the combination of stability with such apparent fragility."[1]

We learn from the same authority that another wire bridge, 640 feet long and 317 high, has been suspended across the gorge of Gotteron. It was finished in 1840. The wire cables are attached immediately to the solid rock on each side, and the point of suspension is higher on one side than on the other, which gives it the appearance of half a bridge. The object of this mode of construction was economy, the expense of building piers of masonry from the bottom of the valley being thus saved.

But even the Freyburg Suspension Bridge has been excelled by a wire bridge recently constructed over the Niagara River in North America. It is built over the river at a point about 1¾ mile below the Falls, and directly over the fearful rapids which commence at this point. The bridge is nearly 800 feet in length, and is suspended 260 feet above the river. Upon the very edge of the precipice which bounds each shore of the river towers 80 feet high have been built, and at a point about 100 feet in their rear the immense wire cables which sustain the bridge are firmly secured. These strands pass from their fastenings immediately over the top of the tower upon either cliff; they pass thence across the chasm, and then over the top of the tower upon the opposite shore, in the rear of which the ends are fastened into the rocks. Two of these powerful cables, one on each side, support the bridge. "Stepping upon the bridge, before you walk 20 feet from the shore you find yourself suspended in the air several hundred feet above a mass of jagged and flinty rocks over and among which the waters of Niagara plunge with terrific velocity. To add to the sensations of terror which this fearful scene is calculated to produce at first glance, you find the bridge oscillating and bending beneath your weight. It requires considerable nerve to cross this aërial structure, and there are few who have firmness enough to look over the side into the awful surf. The bridge is about 10 feet in width, and a temporary railing of wire and slats of wood has been constructed at each side. The flooring is composed of light planks resting upon thin scantlings, to which the wires are fastened."[2]

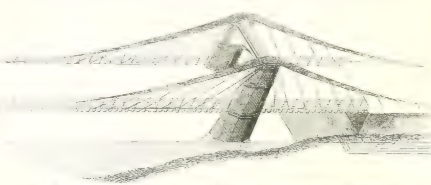

FIG. 328.—[illegible] VIEW OF ONE HALF OF A SUSPENSION BRIDGE AT BALLOCH FERRY, LOCH LOMOND.

Mr. Dredge of Bath has adopted a new principle in the construction of suspension bridges, which, it was supposed, would produce an elegant effect, with economy of material and stability and strength of structure. (Fig. 329.) In this invention the chains are made of sufficient magnitude and strength at the points of suspension, to support, it was supposed, the greatest permanent and contingent load to which they were likely to be exposed; and from thence they taper or diminish gradually to the middle of the bridge, where the strain becomes least. The suspending rods or bars that support the platform, instead of being hung vertically

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(1) Murray's "Handbook for Travellers in Switzerland," &c. See also Penny Magazine, Nos. 270, 281.

(2) "New York Herald," quoted in the "Athenæum," Sep. 30, 1848.

or at right angles to the plane of the horizon, as is usually done, are inclined to it in angles which vary in magnitude from the abutments to the middle of the bridge, where the obliquity, as well as the stress upon the chains, attains its minimum value. It was stated at the time when the invention was introduced, that "much judicious management is necessary on the part of the engineer, to fix upon that degree of obliquity which shall produce the greatest effect. Each bar is considered to perform its part in supporting the load, in proportion to its distance from the abutment, drawn into the sine of the angle of its direction, so that the entire series of suspending bars transmits the same tension to the points of support as would be transmitted by a single bar reaching from thence to the middle of the bridge."[1] Experience, however, has proved that bridges on this principle are deficient in resisting power to horizontal as well as transverse waves just at the points where their action is greatest, so that in some of the bridges on this principle in the Regent's Park, London, for example, the platforms have had to be supported by a timber framing.

Section VI.—On Iron, Girder, and Tubular Bridges.

The extensive employment of iron at the present day, is one of the consequences of the improvements which have taken place in its manufacture, as well as the increased facilities for transit afforded by canal navigation, roads, railroads, and other means of conveyance. It is scarcely more than 70 years ago, that the first iron bridge was constructed in England, over the river Severn, near Coalbrook Dale. It consists of 5 ribs of cast-iron supporting perpendicular spandril pieces of the same material, and upon which the roadway is carried. The arched ribs are nearly semicircular, having a span of 100 feet and a rise of 45 feet. The arches spring at a height of 10 feet above low-water level, so that the clear height up to the soffit of the arches is 55 feet. The form of this bridge is well adapted to the high banks of the Severn, at the place where it crosses. The bridge was built by Darby, but the design appears to have originated with Mr. Pritchard.

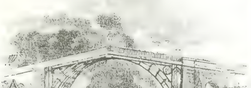

Fig. 330. Iron Bridge at Coalbrook Dale.

In 1787, Thomas Paine presented to the Academy of Sciences, at Paris, a model of an iron bridge constructed by him; and in the following year, during his residence at Rotherham in Yorkshire, a bridge chiefly of wrought-iron is said to have been erected, but was afterwards taken down.

In 1790 Mr. Rowland Burdon designed a cast-iron arch for the River Wear at Sunderland, on a peculiar plan of construction, for which he obtained a patent. It consisted in "a certain mode or manner of making, uniting, and applying cast-iron blocks, to be substituted in lieu of key-stones in the construction of arches." In this way it was proposed to retain the common form and principles of the old stone arch. The Sunderland bridge consisted of six ribs, 240 feet in span, with a rise of 30 feet. The total height from low-water level to the soffit of the arch is nearly 100 feet, and the design is peculiarly elegant and bold. The six ribs which form the arch are parallel to each other, and 6 feet apart. Each rib consists of 105 separate blocks or castings, 5 feet in depth, connected together with bars and collars of malleable iron. The ribs are braced together with cast-iron tubular braces and straps. The spandrils are filled in with cast-iron circles, Fig. 332, meeting at their peripheries, and supporting the roadway, which is formed upon a strong timber frame, planked over and covered with a mixture of chalk and tar, upon which is placed a layer of marl, limestone and gravel. The bridge is 30 feet wide; the abutments are of stone founded on rock, and are 24 feet thick, and from 37 to 42 feet wide. The iron work consists of 214 tons of cast, and 46 tons of malleable iron. The bridge was completed within three years, at a total cost of 26,000*l*. In October 1816, it was disposed of in a lottery for 30,000*l*. The confined situation of the site rendered it necessary to erect the bridge without interrupting the passage of

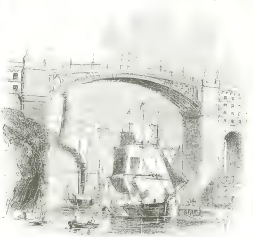

Fig. 331. Iron Bridge at Sunderland.

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[1] The Mathematical principles of the Inclined Suspension Bridge are investigated in a very elegant Paper in Vol. i. of Mr. Weale's large work on bridges.

ships with their rigging standing. For this purpose, a perpendicular scaffolding was raised upon piles in the middle of the river, a sufficient space being left on each side for the vessels. The centre for supporting the arch was fixed on this scaffolding. Some time after the centre was removed, the arch was found to have moved in a horizontal direction eastward, forming a curve of 12 to 18 inches versed sine. This dangerous and unexpected occurrence was skilfully counteracted by introducing transverse and diagonal tie-bars and braces, assisted by screws and wedges, by which the whole was restored to its original position.

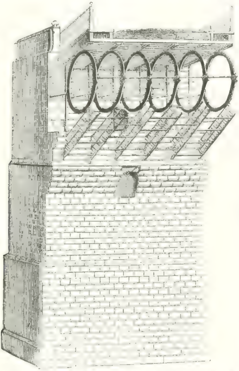

Fig. 352. SECTION OF THE IRON BRIDGE AT SUNDERLAND, 20 FEET FROM THE NORTHERN ABUTMENT.

Several iron bridges were erected by Telford, the first of which was that across the Severn, at Buildwas, in Shropshire, consisting of a single arch, 130 feet in span, with a versed sine or rise of 27 feet. The arch consists of 3 ribs, 9 feet apart, or 18 feet wide from out to out. These ribs are 3 feet 10 inches in depth, and connected transversely by tie-bars. The spandrils for supporting the roadway are formed of vertical bars of cast-iron, and the abutments are of stone.

The largest iron-arch bridge is the Southwark Bridge over the Thames, at London. It was designed and erected by Rennie. It consists of 3 arches, all segments of the same circle; the centre arch being 240 feet in span, with a rise of 24 feet, and the two side arches being each 210 feet in span, with a rise of 18 feet 10 inches. The piers are 24 feet thick; the width of the roadway over the bridge is 28 feet, and the footways on either side are each 7 feet in width. Each arch consists of 8 ribs, and each rib of 15 pieces, of such a depth that the rib is 6 feet deep at the crown, and 8 feet deep at the springing. The metal is 2½ inches thick in the middle, and 4¼ inches at the top and bottom of the ribs. The ribs are connected transversely by cast-iron tie-braces, of the same depth as the ribs, but open in the centre of each; and in the diagonal direction the ribs are connected by another series of ribs, so that each arch consists of a series of hollow masses or voussoirs, similar to those of stone bridges. All the segmental castings forming each arch, as well as the transverse and diagonal tie-braces, are kept in their places by dovetailed sockets, and long cast-iron wedges, thus obviating the necessity for bolts. The spandrils are composed of cast-iron diagonal framing, and the roadway is formed upon cast-iron plates, resting upon the spandrils, and joined with iron cement. The abutments and piers are of stone, built upon platforms of timber, and surrounded by guard or sheathing piles, driven into the bed of the river. In the erection of the bridge, the ribs were commenced in the centre of the span, and continued regularly on both sides towards the piers and abutments. Upon these, connecting and bed plates were secured in the masonry, and when the last segment of each rib was fixed, 3 wedges of cast-iron, each 9 feet long and 9 inches wide, were introduced behind each rib, and nicely fitted and adjusted to them. These wedges were formed with a very slight taper, and were driven simultaneously with heavy hammers, so that the arches were nearly lifted from the centres, which were thus readily removed. The whole of the iron-work had been so carefully prepared, that, when the work was completed, scarcely any sinking of the arches could be detected. It was found, from experiments made during the progress of the works, that the average effect of the expansion caused by the summer increase of temperature was a rise of the arches, to the extent of about 1½ inch at the crown, the abutments being fixed points. The weight of metal in the centre arch was 1,665 tons; in the two side arches, 2,920 tons; making a total of 4,585 tons. The first casting for this bridge was run on the 1st January, 1815, and the bridge was opened 25th March, 1819.

Iron-arch bridges are the same in principle as arch-bridges of stone and other materials, which derive their strength and stability by transferring the effect of the loads placed upon them to the abutments. But "when the peculiar properties of cast-iron had been studied, with a view to its extended application in buildings, and the proportions had been correctly determined for beams of this material, intended to supersede horizontal beams of wood, their employment in the formation of bridges of limited span soon followed; and in the railway works executed during the last twenty years, we have numberless examples of cast-iron girder-bridges, as we have also of cast-iron arch-bridges, of considerable dimensions, and great ingenuity of design and arrangement. The cast-iron girder-bridge, depending for its strength upon the sectional area of the girder, at that point in its length over which the weight or load acts, requires abutments to resist vertical pressure only; while the abutments of arch-bridges have to resist the lateral thrust of the arch. In the cast-iron girder-bridge, moreover, the depth of the structure is reduced to that of the section of material due to the maximum load; and hence the peculiar applicability of this form for railway bridges, in which it is desirable to preserve a minimum distance from the under side or soffit of the girder to the level of the roadway above. But the limitation of span to which girders are safely applicable has always restricted their employment in bridges, and 40 feet has commonly been considered the maximum length of bearing to which single cast-iron girders can be safely applied, liable to be loaded with railway trains, or other heavy weights."[1]

The desire to retain this convenient form of structure, and to extend its use to larger spans, has led to attempts to combine wrought-iron with cast metal; malleable-iron bars or rods being fitted to cast-iron girders, so as to form a kind of metal trussing, the depth of the truss being limited to that of the girder. But the great defect in these compound constructions consists in the difficulty of making the two kinds of iron act fully together in bearing the load. "The strength of cast-iron depends upon its rigidity; for, although it possesses the property of elasticity, this cannot be tasked with safety; and it is well known that repeated deflections will often destroy a casting which has withstood previous pressures with apparent impunity. Malleable-iron, on the other hand, applied in the form of truss-bars to cast-iron girders, is intended to act by the application of its tensile strength; but the effect of this can only be secured when it becomes active *before* the cast-iron girder has suffered any dangerous deflection. It is therefore indispensable that the adjustment of the length of the bars during all changes of temperature shall be strictly preserved,—a condition which is physically impracticable by any known form of construction or arrangement of parts." This defect was fatally illustrated by the failure of the largest bridge of this kind, erected over the Dee, near Chester, on the line of the Chester and Holyhead Railway. On the 24th May, 1847, one of the girders gave way, and the cause of the failure was variously ascribed to a passing train having got off the rails, and to an undue loading of the bridge with additional ballasting.

The first attempts to substitute wrought-iron for cast-iron in the construction of girders were made by joining plates of rolled-iron vertically with rivets, and attaching a strip of angle-iron on each side, both at top and bottom, so as to form artificial flanges, to give the required strength at those parts. Girders thus formed are said to have been applied by Messrs. Fairbairn in the construction of floors, in 1832, and they have been used as deck-beams in ships. Such girders were found liable to yield by twisting or bending laterally; and to obviate this defect, as well as to obtain the great strength and rigidity required in the employment of wrought-iron girders for railway constructions, the tubular form was designed, and T-iron used in forming vertical ribs, so that the side plates might be arranged vertically. Wrought-iron thus applied having been proved by experiment to have less power to resist compression than extension, it was desirable to increase the strength of the upper part of girders constructed of this material, and a separate compartment or cell was formed to obtain this object. These improvements were made by Mr W. Fairbairn, and patented, October 8, 1846. The girders are formed of plates of metal, united by rivets and ribs of rolled-iron: the side plates are put together with but-joints, covered on the outside with stues, or covering-plates, and on the inside with vertical ribs of angle or T-iron, the side plates, stiles, and ribs being riveted together. The top of this hollow beam is formed with two or more rectangular cells, composed of plates arranged vertically, and connected by strips of angle-iron and rivets with the top and side plates. The bottom is formed of iron plates, connected together by covering-plates over the cross-joints, and attached to the side plates by angle-iron and rivets. The top may be constructed either of cast or of malleable iron, and cellular, rectangular, or of an elliptical or any other form, to prevent the top puckering from compression; or other methods may be employed, such as thick metallic castings, or lighter iron plates, arranged so as to form hollow cells. The bottom may also be constructed of a series of plates, either of single or double thickness, riveted together. The joints of the plates alternate or break with each other, and are riveted by a peculiar method which the inventor calls *chain-riveting*, as it forms a chain of plates throughout; and the structure so unites the covering-plates as not to weaken the plates by rows of transverse rivet-holes, but to form a connecting link to each joint by a series of longitudinal rivets or pins. "This useful invention," says Mr. Dempsey, "which comprises the best methods yet devised for uniting the several parts of structures of plate and bar iron, contains also the essential principles upon which tubular girders may be, and have been, constructed, of a size adequate to form bridges within themselves, and admit the interior passage of railway trains or other traffic."

The first wrought-iron tubular girder bridge built under this patent, was over the Leeds and Liverpool Canal, for the purpose of carrying the Blackburn and Bolton Railway. Fig. 333 is an elevation, and Fig. 334 a transverse section of this bridge: Fig. 335 is an enlarged transverse section of one of the outer girders, and Fig. 336 an enlarged longitudinal view of part of one of the girders, showing a section of one of the cross timbers on which the railway is supported. The span of this bridge is 60 feet, and each girder is 66 feet in total length, the bearings of the masonry being each 3 feet long. The two lines of rails are carried between three parallel girders, G, each of which consists of a

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(1) "Tubular and other Iron Girder Bridges," &c. By G. Drysdale Dempsey, C.E. This valuable little volume, forming one of the numbers of Mr. Weale's Rudimentary Series, has been of great assistance in the preparation of this Section.

rectangular top compartment, c, composed of plates $\frac{3}{8}$ inch thick, and riveted at the internal corners to

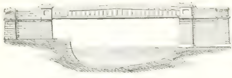


Fig. 333.

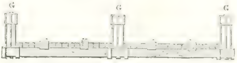


Fig. 334.

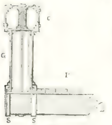


Fig. 335.

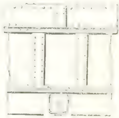
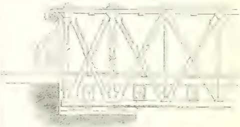


Fig. 336.

angle-irons; of side plates $\frac{5}{16}$ inch thick, joined vertically by rivets to T-iron ribs, and also riveted to the bottom plate of the top compartment, and its internal angle-irons, through longitudinal ribs of angle-iron, placed externally; and of double bottom plates, each $\frac{3}{8}$ inch thick, joined by rivets to external longitudinal strips of angle-iron. The rails are laid upon longitudinal timbers, which, with intermediate planking, are supported upon transverse beams of wood suspended by double straps of wrought-iron, which pass upwards through the bottom plates of the girders, and are secured by screw nuts. A vertical bolt of wrought-iron also passes through a cast-iron socket in the top compartment of the girder, and downward through each cross-beam, below which it is fixed with a washer-plate and screwed nut. This structure on being tried by severe tests was found equal to any weight to which it could be subjected. Three locomotives, each weighing 20 tons, occupying the entire span of 60 feet, were run together as a train, at rates varying from 5 to 25 miles an hour, and produced a deflection in the centre of the bridge of only .025 of a foot. Two wedges of the height of 1 inch were then placed on the rails in the middle of the span, and the dropping of the engines from this height, when at a speed of 8 or 10 miles per hour, caused a deflection of only .035 of a foot, which was increased to .045 of a foot, or nearly half an inch only, when wedges 1½ inch in thickness were substituted. A bridge of this kind of 60 feet span, containing 30 tons weight of iron, cost only 900*l.*; whereas a cast-iron trussed girder bridge of the same, required 76 tons of cast-iron, and 14 tons of wrought-iron, and cost 1,432*l.* 16*s.*

Malleable-iron has also been applied in various other forms ot combination to the construction of bridges. The Patent Iron Bridge suggested by Mr. George Smart in 1824, consisting of a combination of wrought-iron bars, arranged in a diagonal form, is the parent of the numerous *lattice-bridges* so common in America. These present a vertical framing perfectly horizontal on its upper and lower lines, and composed of iron bars crossing each other in a diagonal direction, forming angles of about 18° with the horizon. (Fig. 337.) The framing also comprises vertical or *hanging-bars*, and *base*-bars forming the lower horizontal lines of the framing, and also passing horizontally over each alternate row of intersections of the diagonal bars. Each bar is forged of enlarged width at the points of intersection, through which bolts are fixed to connect the whole together. Two of these trussed frames erected vertically and parallel to each other form the supports of the roadway to be formed between them, the two frames being tied together by transverse connecting rods, the roadway or flooring being situated near the top of the frames, and never on the lower bars, which Mr. Smart regarded as an erroneous practice in wooden bridges. Between the frames, cross-braces, consisting of two light bars, are fixed, bolted together and fitted to the connecting rods. A lattice bridge of wrought-iron erected across the line of the Dublin and Drogheda Railway is 84 feet in clear span. Fig. 337 is a portion of a lattice bridge erected by Mr. Osborne on the Waterford and Limerick Railway.



Mr. Dempsey points out an important distinction between the simple lattice or diagonal framing, and the roof framing. In the former, the strength is obtained by the connexion ɔf the bars at each intersection, while the abutting principle of the roof is disregarded. The strain is therefore borne wholly by the rivets or pins which pass through the crossing bars, and the effect of this strain is shown in the gradual loosening of the pins. The bars are also considerably weakened by the holes through the middle of them, and in wooden lattice bridges, fracture and failure of the material have often resulted. The lattice principle has been considerably improved upon by Mr. R. B. Osborne, C. E., by the introduction of a top and bottom chord of malleable-iron with intermediate braces of cast-iron in the form of rectangular tubes.

For other forms and applications of tubular beams and girders, we must refer to Mr. Dempsey's work, and pass on to notice the grand application of the hollow girder or tube in the Conway and Britannia

Bridges, on the line of railway from Chester to Holyhead. The first of these tubular bridges was required for carrying the railway over the river Conway, and at about 18 miles further on, the separation of the Island of Anglesea from the main land of Caernarvonshire by the straits of Menai, gave occasion for the bolder structure of which the central pier is skilfully based on a rock, termed the Britannia Rock, from which the bridge derives its name.

It was the original intention of Mr. Robert Stephenson, the engineer of the works, to have crossed the straits with a cast-iron arched bridge, in two spans of 450 feet each, the height of the arches to be 100 feet from the level of the water to the crown of the arch, and the springing 50 feet from the level. As it was necessary that the water-way should not be interrupted by scaffolding or centering, it was proposed to fix the half-arches in each side of the central pier in portions simultaneously, and connect them with tie-rods, so that the weight on either side should balance that on the other.

This design for an arched bridge was frustrated by a condition insisted on by the Lords Commissioners of the Admiralty, as conservators of the navigation: viz. that the clear height of water-way under the lowest part of the arches, or their springing, should not be less than 105 feet. To have complied with this condition, the whole structure must have been raised 50 feet above the proposed position, thereby involving an immense additional cost in the piers and abutments, besides being irreconcilable to the adjoining levels of the railway. The engineer, therefore, abandoned the arched form altogether, and "conceived the original idea of a huge tubular bridge, to be constructed of riveted plates of wrought-iron, and supported by chains, and of such dimensions as to allow of the passage of locomotive engines and railway trains through the interior of it." In April, 1845, Mr. Stephenson obtained the assistance of Mr. William Fairbairn in carrying out his scheme. The first idea seemed to be, that the tube should be either of a circular or an egg-shaped sectional form, and that it should act by its rigidity and weight as a stiffener, and prevent, or, at least to some extent, counteract, the undulations due to the catenary principle of construction. Mr. Fairbairn appears from the first to have been opposed to the application of chains, even as an auxiliary. "I always felt that, in a combination of two bodies, the one of a perfectly rigid, and the other of a flexible nature, there was a principle of weakness; for the vibrations to which the one would be subjected would call into operation forces whose constant action upon the rivets and fastenings of the other could not but tend to loosen them, and thus, by a slow, but sure agency, to break up the bridge."[1]

But Mr. Stephenson wisely determined that these and all other points should be submitted to the test of an elaborate experimental inquiry, to determine, *first*, the peculiar sectional form which should be given to the tubes, and, *secondly*, the distribution and dimensions of the material which would ensure the required strength and rigidity of the entire structure. These experiments were conducted by Mr. William Fairbairn, assisted at a later period, dating from the 19th September, 1845, by Mr. Eaton Hodgkinson; the details and results of which were reported to Mr. Stephenson, who appended them to his own report, presented to the directors of the railway company in February 1846. An account of these experiments is given in Mr. Fairbairn's work, and an abstract of them is given in Mr. Dempsey's little volume. Experiments were made on the strength of iron tubes of various forms: Mr. Fairbairn's object being first directed to test the principle, originally suggested by Mr. Stephenson, of a structure every part of which, although rigid, should be brought into a state of tension, and whose strength should consist not as that of a beam or girder does in its resistance to extension on the one side and to compression on the other, but in a resistance to extension on both sides. It was found in the early experiments that the weakness of the tube was in its upper surface, which yielded to compression before the under side was upon the point of yielding to extension. Experiments were then made with a view to strengthen the upper surface, so that it should not be on the point of yielding to compression until the under surface was about to yield by extension. "This state of the tube was a necessary condition to the greatest economy of its material, for in any state in which it was not on the point of yielding on the one side at the instant when it was on the point of yielding on the other, some of the material might be taken from the stronger side without causing that to yield and added to the weaker so as to prevent that side from yielding, and thus the tube would be rendered stronger by a new distribution of its material. It was with reference to this principle that the rectangular form of section had suggested itself to me, in the place of the circular or the elliptical forms proposed by Mr. Stephenson, and that I had ordered the top of the tube to be thickened. It now occurred to me that the top might be strengthened more effectually by other means than by thickening it, and I directed two additional tubes to be constructed, the one rectangular, and the other elliptical, with hollow triangular cells or flues to prevent crushing. These experiments led to the trial of the rectangular form of tube with a corrugated top, the superior strength of which decided me to adopt that cellular structure of the top of the tube which ultimately merged in a single row of rectangular cells. It is this cellular structure which gives to the bridges now standing across the Conway Straits their principal element of strength."

On the 9th February, 1846, Mr. Stephenson made his Report to the Directors of the Chester and Holyhead Railway, in which he gives a summary of Messrs. Fairbairn and Hodgkinson's experiments. "The first series of experiments," he says, "was made with plain circular tubes, the second with

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(1) "Conway and Britannia Tubular Bridges." By William Fairbairn C.E. London 1849.

elliptical, and the third with rectangular. In the whole of these, this remarkable and unexpected fact was brought to light,—viz. that in such tubes the power of wrought-iron to resist compression was much less than its power to resist tension,—being exactly the reverse of that which holds with cast-iron: for example, in cast-iron beams for sustaining weight, the proper form is to dispose of the greater portion of the material at the bottom side of the beam,—whereas with wrought-iron these experiments demonstrate beyond any doubt, that the greater portion of the material should be distributed on the upper side of the beam. We have arrived therefore at a fact having a most important bearing upon the construction of the tubes; viz. that rigidity and strength are best obtained by throwing the greatest thickness of material into the upper side. Another instructive lesson which the experiments have disclosed is, that the rectangular tube is by far the strongest, and that the circular and elliptical should be discarded altogether. This result is extremely fortunate, as it greatly facilitates the mechanical arrangements for not merely the construction, but the permanent maintenance of the bridge."

Appended to Mr Stephenson's Report are separate Reports, the one by Mr. Fairbairn and the other by Mr. Hodgkinson. Mr. Fairbairn remarks that "with tubes of a rectangular shape, having the top side about double the thickness of the bottom, and the sides only half the thickness of the bottom, or one fourth the thickness of the top, nearly double the strength was obtained. In experiment 14, a tube of the rectangular form, 9½ inches square, with top and bottom plates of equal thickness, the breaking weight was . . . . 3,738lbs.

Riveting a stronger plate on the top side, the strength was increased to 8,273lbs.

The difference being . . 4,535lbs.;

considerably more than double the strength sustained by the tube when the top and bottom sides were equal. The experiments given in No. 15 are of the same character, where the top plate is as near as possible double the thickness of the bottom. In these experiments the tube was first crippled by doubling up the thin plate on the top side, which was done with a weight of . . . . 3,788lbs.

It was then reversed with the thick side upwards, and by this change the breaking weight was increased to . . . . 7,148 lbs.

Making a difference of . 3,360 lbs.;

or an increase of nearly double the strength, by the simple operation of reversing the tube, and turning it upside down.

"The same degree of importance is attached to a similar form when the depth in the middle is double the width of the tube. From the experiment (No. 16) we deduce the same results in a tube where the depth is 18½ and the breadth 9¼ inches. Loading this tube with 6,812lbs. (the thin plate being uppermost,) it follows precisely the same law as before, and becomes wrinkled with a hummock rising on the top side, so as to render it no longer safe to sustain the load. Take, however, the same tube and reverse it with the thick plate upwards, and you not only straighten the part previously injured, but you increase the resisting power from 6,812 lbs. to 12,188lbs. Let us now examine the tube in the 29th experiment, where the top is composed of corrugated iron, forming two tubular cavities extending longitudinally along its upper side. This, it will be observed, presents the best form for resisting the *puckering* or crushing force, which on almost every occasion was present in the previous experiments. Having loaded the tube with increasing weights, it ultimately gave way by tearing the sides from the top and bottom plates, at nearly one and the same instant after the last weight, 22,469lbs. was laid on. The greatly increased strength indicated by this form of tube is highly satisfactory; and provided these facts be duly appreciated in the construction of the bridge, they will, I have no doubt, lead to the balance of the two resisting forces of tension and compression."

Referring to the suspension-chains which had been proposed as an additional element of security in the bridge, Mr. Fairbairn remarks, that "although suspension-chains may be useful in the construction, in the first instance, they would nevertheless be highly improper to depend upon as the principal support of the bridge. Under every circumstance, I am of opinion that the tubes should be made sufficiently strong to sustain, not only their own weight, but, in addition to that load, 2,000 tons equally distributed over the surface of the platform; a load ten times greater than they will ever be called upon to support. In fact, it should be a huge sheet-iron hollow girder, of sufficient strength and stiffness to sustain these weights; and, provided the parts are well proportioned, and the plates properly riveted, you may strip off the chains, and leave it as a useful monument of the enterprise and energy of the age in which it was constructed."

In the Table at the top of the next page, some of the data and the results of experiments upon rectangular tubes are brought together.

When the course of these experiments had indicated the form of tube which must actually be employed for the bridge, a model tube was constructed, as nearly as possible one-sixth the dimensions of the proposed tubes across the Menai Straits. The apparatus used for experimenting upon it is shown in Figs. 338 and 339. Fig. 339 represents at A a side-view, 75 feet between the supports; B is the platform supporting the weights, suspended from two cross-bars passing through the sides, and resting upon the outside angle-iron and the bottom of the tube, as shown in Fig. 338 at *a a*. C C is a balk of timber, passing under the cross-links *b b*, which, on being raised by two powerful screw-jacks *e e*, lifted the load from off the tube, in order to ascertain the effects of the successive loads upon the elastic powers of the tube. The temporary supports D D were only used

Experiments.		Length of Tubes between the Supports		Depth	Width	Area of Transverse Section	Thickness of Plates.		Ultimate Deflection.	Breaking Weight	Manner of yielding
							Top.	Bottom			
Class.	No	Feet.	In.	In.	In.	In.	In.	In	In	lbs.	
H.	15	17	6	9.6	9.6	92.16	.075	.075	1.10	3,738	By compression.
	16						.272	.075	1.13	8,273	By extension
	17						.075	.112	0.94	3,788	By compression.
	18						.112	.075	1.88	7,148	By extension.
I.	19	17	6	18.25	9.25	168.81	.059	.149	0.93	6,812	By compression.
	20						.149	.059	1.73	12,188	Ditto.
	21	18	0	13.25	7.50	99.37	.142	.142	1.71	13,680	Ditto.
	22	24	0	15.00	9.25	138.75	.160	.160	2.66	17,600	Ditto.
K.	23	18	6	13.00	8.00	104.00	.066	.066	1.19	8,812	Ditto.
	24	19	0	15.40	7.75	119.35	.230	.180	1.59	22,169	Sides distorted.

for the purpose of receiving part of the falling load, in case of accident or the rupture of the tube. It

Fig.

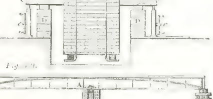
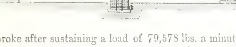


Fig. 9.



broke after sustaining a load of 79,578 lbs. a minute and a half, the bottom plate tearing asunder two feet from the centre of the shackle.

All these experimental trials were conducted by hanging a dead weight to the tubes under trial. The mechanical effect of such a weight is much less injurious than a weight passing over or through it with greater or less velocity, as in the case of a railway train. The commissioners appointed by her Majesty's Commission, of the 27th August, 1848, to inquire into the conditions to be observed by engineers in the application of iron to structures exposed to violent concussions and vibration, &c., investigated this subject experimentally. They constructed an apparatus by means of which a loaded car was allowed to run down an inclined plane: the iron bars which were the subject of the experiment were fixed horizontally at the bottom of the plane, in such a manner that the loaded car would pass over them with the velocity acquired in its descent. Thus, the effects of giving different velocities to the loaded car, in depressing or fracturing the bars, could be observed, and compared with the effects of the same loads, placed at rest upon the bars. Thus, for example, when the carriage, loaded to 1,120 lbs., was placed at rest upon a pair of cast-iron bars, 9 feet long, 4 inches broad, and 1½ inch deep, it produced a deflection of $\frac{6}{10}$ths of an inch; but when the carriage was caused to pass over the bars at the rate of 10 miles an hour, the deflection was increased to $\frac{8}{10}$ths, and went on increasing as the velocity was increased; so that, at 30 miles per hour, the deflection became 1½ inch; that is, more than double the statical deflection. "Since the velocity so greatly increases the effect of a given load in deflecting the bars, it follows, that a much less load will break the bar when it passes over it than when it is placed at rest upon it; and accordingly, in the example above selected, a weight of 4,150 lbs. is required to break the bars, if applied at rest upon their centres; but a weight of 1,778 lbs. is sufficient to produce fracture, if passed over them at the rate of 30 miles an hour. It also appeared that, when motion was given to the load, the points of greatest deflection, and, still more, of the greatest strains, did not remain in the centre of the bars, but were removed nearer to the remote extremity of the bar. The bars, when broken by a travelling load, were always fractured at points beyond their centres, and often broken into four or five pieces, thus indicating the great and unusual strains they had been subjected to."[1]

Engineers have generally supposed that the deflection caused by passing a weight at a high velocity over a girder is less than the deflection which would be produced by the same weight at rest; and even when they have observed an increase, they have attributed it solely to the jerks of the engine or train, produced by passing over inequalities at the junction of the rails, or other similar causes. For the purpose of examining this question, the commissioners submitted two actual bridges to the test of experiment. One was the Ewell Bridge, on the Croydon and Epsom line, and the other the Godstone Bridge, upon the South-Eastern line, both constructed to carry the railway over a road. "A scaffold was constructed, which rested on the road, and was therefore unaffected by the motion of the bridge, and a pencil was fixed to the under side of one of the girders of the bridge, so that when the latter was deflected by the weight of the engine or train, either placed at rest or passing over it, the pencil traced the extent of the deflection upon a drawing-board attached to the scaffold. An engine and tender were made to traverse the bridges at different velocities, or to rest upon them, at pleasure. The span of the Ewell Bridge is 48 feet, and the statical deflection due to the above load rather more than $\frac{1}{5}$th of an inch. This

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(1) "Report of the Commissioners appointed to inquire into the application of Iron to R[illegible]

was slightly but decidedly increased when the engine was made to pass over the bridge; and, at a velocity of 50 miles per hour, an increase of $\frac{1}{7}$th was observed. As it is known that the strain upon a girder is nearly proportional to the deflection, it must be inferred, that, in this case, the velocity of the load enabled it to exercise the same pressure as if it had been increased by $\frac{1}{7}$th, and placed at rest upon the centre of the bridge. The weight of the engine and tender was 39 tons, and the velocity enabled it to exercise a pressure upon the girder equal to a weight of about 45 tons. Similar results were obtained from the Godstone Bridge."

With respect to the best qualities and mixtures of iron for girders, it appears that engineers have no guarantee that the mixture for which they have stipulated in a contract shall be that used by the founder, and no certain test by which to determine whether a given piece of iron has been manufactured by hot blast or cold blast. Mr. Fox recommends, as a good protection, "that engineers, in contracting for a number of girders, should stipulate that they should not break with less than a certain weight, (leaving the mixture to the founder,) and cause one more than the required number to be cast. The engineer may then select one to be broken, and, if it break with less weight than that agreed upon, the whole may be rejected."

The details which are now about to be given will refer chiefly to the construction of the Britannia Bridge. The Conway Bridge was erected within a few feet of Telford's suspension bridge, and close beneath the walls of Conway Castle. It consists of one span only, of 400 feet clear width, and two abutments of masonry, of which the design is in harmony with that of the castle.

The site selected by Mr. Stephenson for carrying his tubular bridge over the Menai Straits was determined by a mass of rock, occupying the centre of the stream, and of suitable dimensions to serve as the foundation of a central pier, and standing considerably above the level of low water. The distance of this rock, and of the bridge now built over it, from the great suspension bridge of Telford, is one mile lower down the straits, or in a southern direction. On the Caernarvon side, the shore rises abruptly from the water's edge, and shelves upward with a gentle inclination; so that a horizontal line passing at an elevation of 100 feet over the water, is, when extended about 400 feet inland from the water-line, only a few feet above the natural surface of the ground. On the Anglesea side, the rocky surface extends for a considerable distance, and, at a length of about 250 feet from the water-line, the surface is from 80 to 90 feet below the horizontal line just described. Hence, the embankment required to continue the railway from the Anglesea end of the bridge is much higher and more extended than that at the Caernarvon end. The Britannia Rock, which rises from near the middle of the bed of the strait, is covered at high water to a depth of 10 feet, and stands at low water about 10 feet above it. A tower of masonry is erected on this rock, and at the clear distance of 460 feet from it, at the limits of the water-way, another tower is built on either side of it, Fig. 340. At the distance of 230 feet from each of these towers is a continuous abutment of masonry, 176 feet in length. The sides of these five stupendous masses of masonry are tapered with a straight batter. The Britannia tower is 62 feet by 52 feet 5 inches, at the base, and is reduced by the batter to 55 feet 5 inches at the height of 102 feet above high-water line, at which level the tubes pass through it. A plinth extends round the base of this and the other towers; and the height of this tower above high-water level is 200 feet, or nearly 230 feet from the bottom of the foundation on the rock. The stone used for the external parts of all the masonry is a hard and durable limestone, known as *Anglesea marble.* The interior of the masonry is a soft red sandstone, quarried at Runcorn, in Cheshire. The Britannia tower is constructed with hollow spaces or chambers within it. The total weight of the masonry in this tower is about 20,000 tons, and about 387 tons of cast-iron, in beams and girders, are built in it. The foundations were laid, and the work constructed up to the level of high-water, during the intervals of the tide. The stones in the whole of the masonry were left with the quarry or rough face, except at the angles, where they were dressed to a square arris, and in the recesses and top entablature, where they were dressed to a fair face all over. The Anglesea and

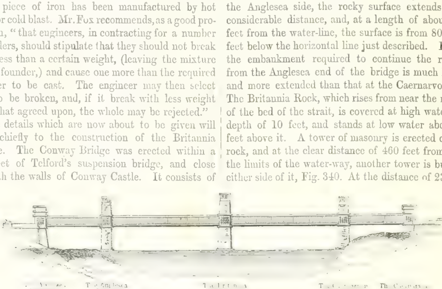


Fig. 340. ELEVATION OF THE BRITANNIA TUBULAR BRIDGE.

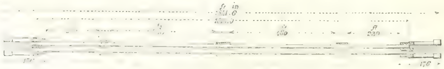


Fig. 341. PLAN OF THE BRITANNIA TUBULAR BRIDGE.

Caernarvon towers have the same dimensions at the base as the Britannia tower, but the height is 10 feet less. The abutments are 176 feet in length, and of a width corresponding to the towers, viz. 55 feet at the level of the bottom of the tubes. The continuations of the abutments are surmounted with parapet walls of solid masonry and of considerable height, each of which terminates at the extremity of the bridge with a projecting pedestal, on which a colossal couchant lion faces the approaching visitor. Each lion is composed of 11 pieces of limestone, and measures 25 feet in length and 12 feet in height, weighing about 30 tons. They were executed by Mr. Thomas.

The four spaces between the Britannia tower and the other towers, and between these and the abutments, had to be spanned by the iron tubes, and, as each tube serves for only one line of rails, 8 tubes were required, 4 of 460 feet, and 4 of 230 feet, the four longer ones being over the water, and the four shorter ones over the land. Thus it will be understood that each line of way through the bridge is composed of four separate tubes, united together, so that in the double line of railway there are two parallel tubes, each 1,513 feet long. To unite each of the four sections, short lengths of tube were constructed within the towers, which, being united with the main lengths, make up each complete and continuous tube. For the four shorter, or land tubes, scaffolds were erected, and the tubes constructed at once in their final position; but the four main tubes were constructed on timber platforms on the shore, and conveyed in flat-bottomed vessels, or *pontoons*, to the towers, where they were deposited, and raised to their required elevation of 102 feet above high-water level by means of hydraulic presses. In this way, all scaffolding across the straits was avoided, and the interruption of only half the channel at one time was limited to the brief period occupied in raising each tube from the base of the towers.

The site selected for the construction of the 4 main tubes was on the margin of the Caernarvon shore, to the south of the bridge. An intermediate space was occupied with workshops, &c., and cottages were built for the accommodation of about 500 workmen. Four strong stages were erected upon piles, and a continuous platform laid from end to end of the site, Fig. 342, consisting of timber posts and struts, with top stringers and beams, covered with stout planking. A pier of masonry was built at each end extending under each end of the tube for a length of 6 feet, so that when each tube was completed and the platform removed, the tube was entirely supported upon these end piers, and any deflection arising from the weight of the tube could thus be detected. Two lines of rails were laid parallel with the line of each tube, upon which was moved with winches a traversing stage sufficiently wide and high to stride the tube, and along the top of it a small crab, Fig. 343, moving upon wheels, was made to traverse the width of the work, and was thus applied to raise the plates and materials. Portable furnaces accompanied the men employed in riveting.

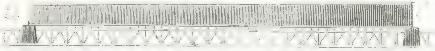


FIG. 342.

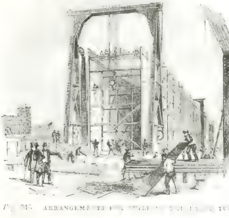


FIG. 343. ARRANGEMENTS FOR BUILDING THE BRITANNIA TUBE

Fig. 344, is a cross section of one of the tubes, showing the general form of construction: the sides are parallel, but the height is slightly varied. The height externally is 30 feet at the centre in the Britannia tower, and this is reduced to 22¾ feet at the extremities in the abutments, the bottom line being horizontal, but the top line forming a parabolic curve, the rise of which thus equals the difference in height, or 7 feet 3 inches. The clear internal height is 26 feet at the centre, and 18¾ feet at the ends. The external width is 14 feet 8 inches, and internally 14 feet, which is further reduced 7 inches by the ribs.

The covering of the tubes consists of malleable iron plates, connected together by rivets with ribs of T and L-iron, besides strips of flat bar iron over the joints. The tubes are strengthened at top and bottom with internal longitudinal tubes or cells, of which there are 8 in the upper part and 6 in the lower. The plates vary in dimensions and thicknesses. The side plates are reduced in thickness from the ends towards the middle of the tube, and those forming the top and bottom are increased in the same direction. The side plates are alternately 6½ feet and 8 feet 8 inches long, and all 2 feet wide. They are arranged vertically, so that the joints occur at every 2 feet; they are $\frac{1}{2}$ inch thick in the middle of the length of the tube, and $\frac{5}{8}$ inch thick at the ends. The top plates are all 6 feet in length and $1\frac{3}{4}$ foot in width, and vary in thickness from $\frac{5}{8}$ inch

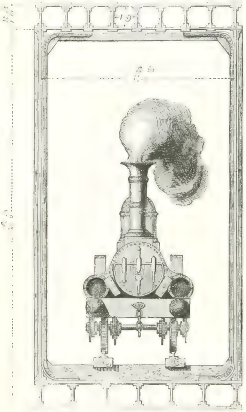


Fig. 344. CROSS SECTION OF ONE OF THE TUBES.

at the ends of the tube to $\frac{3}{4}$ inch in the middle. The bottom plates are 12 feet long and 2 feet 4 inches wide; they are in two layers, and the plates in each are $\frac{7}{16}$ inch thick at the ends of the tube, and $\frac{9}{16}$ inch thick in the middle of the main tubes. The difference in width of the top and bottom plates arises from the difference in the number of cells in the top and bottom of the tube, $1\frac{3}{4}$ foot being the width of each of the 8 top cells, and 2 feet 4 inches that of each of the 6 bottom cells. All the joints of the plates are *but-joints*, Fig. 350, or those which meet at the edges without overlapping. The horizontal joints at the ends of the plates are covered with plates of iron on both sides and firmly riveted through them. The side elevation Fig. 345, will explain this construction. Fig. 346 is a plan of part of the top of the tube, showing the joints in the plates alternating with each other and strengthened with covering plates.

The vertical frames upon which the plates are fixed are chiefly of T-iron. These ribs are bent at right angles at the ends, and extend for about 2 feet along the top and bottom plates of the principal compartments of the tube. The side plates meet with a but-joint over the centre of the rib, and a similar rib being placed on the outside in a reversed position the whole are firmly riveted together. Where the tube passes through the towers, flat bar iron is substituted for the outside T-iron ribs. The vertical joints of the main tubes are strengthened for about 60 feet at each end by a strong plate 9 inches wide, passing at right angles between the edges of the plates, and every sixth rib throughout the entire length is strengthened with an additional plate inside, meeting the edge of the ┬-iron rib.

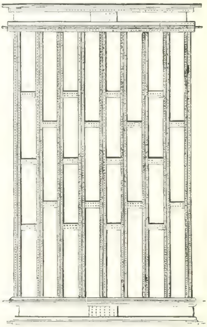


Fig. 345.

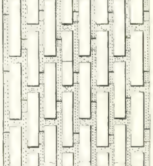
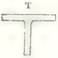
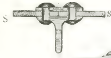


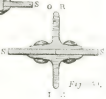
Fig. 346.

Figs. 347, 348 show the sections of ┬-iron and L-iron used for the ribs. The former T is 5 inches wide over the table and $3\frac{1}{2}$ inches deep; the latter L is $3\frac{1}{2}$ inches wide each way. Fig. 349, shows the kind of joint used in connecting the side plates ss of the tube within the towers; P is the outside covering plate; and T the inside rib of T-iron. Fig. 350 shows the ordinary framing of the ribs and side plates: S S are the side plates of the tube; O R the outside and I R the inside ribs of T-iron. Fig. 352 represents the framing of 30 of the vertical joints at each end of the main tubes, showing the central plate against which the ends of the side plates are fitted with the 4 L-iron ribs in the angles, the whole of which are firmly riveted together. Fig. 353 shows the framing adopted at every sixth of the vertical ribs, or every 12 feet distance throughout the main tubes. S S are the side plates of the tube; T the outside rib of T-iron; A A the flitches of plate iron; and B the filling-in plate, riveted between them. Fig. 351, is a perspective sketch of a portion of one of the ordinary vertical joints, showing a portion of two side plates meeting at the centre of the inside and outside ribs, and also the manner in which the joints of the T-iron ribs are strengthened with side pieces of L-iron and riveted through them.

Fig. 347







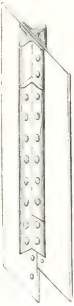
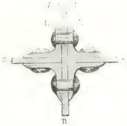
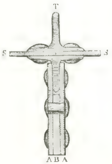


Fig. 351.





The angles of the principal compartment of each tube are strengthened with *gussets*, or triangular plates of iron riveted through the ribs of T-iron. See Fig. 344. At every sixth rib the gussets are of larger dimensions, or about 5 feet in height and $1\frac{3}{4}$ foot in width.

The cells are formed with vertical partitions of plate-iron, connected at the angles with the upper and lower plates by horizontal ribs of L-iron fitted to the angles and firmly riveted. The top and bottom edges of the side plates of the tube are also riveted to the horizontal plates, forming the cells through ribs of L-iron in the angles.

The rails for the railway, Fig. 344, are supported in chairs upon continuous longitudinal timbers, which are supported upon pieces of L-iron, reversed so as to form brackets, and riveted through plates of iron 9 inches wide, set on edge and fixed across the tube at intervals, and secured to the vertical T-iron ribs, and the plates forming the top of the lower cells.

The rivets are about an inch in diameter, and arranged in rows, 3 inches apart in the vertical joints, and 4 inches in the horizontal. The rivets were heated in portable furnaces, and were taken up with tongs, and being placed in the holes punched for them, the ends were firmly clenched or riveted before cooling, with heavy hammers. The rivet-head thus formed was then finished by hammering a steel cup-shaped tool upon it, and the contraction of the length of the rivet in cooling, drew the plates closely together with considerable force. About 2,000,000 rivets were used in the entire work. The holes were punched in the plates by a beautiful machine invented by Mr. Roberts on the principle of the Jacquard loom. Large portions of the plating for the tubes were put together partially on the platforms, and being raised to their places by means of the stages and tackling, were speedily fixed in their true positions, and required only to be riveted to complete their connexions.

The tubes in passing through the towers and abutments were supported on rollers, a set of which is represented in Fig. 354. Each set, consisting of 22 rollers, was arranged in a frame in two parallel rows, the axes projecting through holes in the frame. One of these frames was placed under each side of each end of each tube, so that 32 sets of rollers and frames

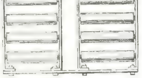


Fig. 354.

were employed. The depth of the frame was less than the diameter of the rollers (which was 6 inches), so that it was not in contact with the cast-iron plates placed upon the rollers. This will be understood by referring to Fig. 362, which is a front view of these plates, *m m*, and of the intermediate rollers and frame. The under roller-plate rests in a bed of wood, and the upper roller plate, in which the tube rests, is thus free to move according to the expansion or contraction which it undergoes.

The ends of the tubes are further supported by an apparatus of cast-iron girders and balls of gun-metal applied in the following manner:—longitudinal girders are attached to the projecting ends of cross girders built in the walls of the towers: these longitudinal girders are formed with a groove or channel in the upper surface, in which the gun-metal spheres 6 inches in diameter are free to move. Similar girders are placed over these, with a corresponding groove on their under side, and thus free to move over the spheres. Upon these upper girders, transverse girders are fixed, which pass over the tube and are fixed to it with strong bolts 3 inches in diameter, which stand up vertically along the tube, bolted to its side, and, passing through holes cast in the transverse girders, are secured to them with screwed nuts. The ends of the tubes in the towers are stiffened with cast-iron frames of considerable dimensions.

The following is the weight of a single line, and the number of rivets, together with the sectional areas at the centre of the large tubes:—

	Tons.	Sectional Area.	Number of Rivets.
Top	1,481	648.25 sq. in.	310,390
Sides	1,727	302.00	535,650
Bottom	1,472	585.43	249,010
	4,680	1535.68	1,095,050

The floating of the main tubes from the building stage to the base of the towers required much previous arrangement. As each tube was completed, it was left to bear upon the piers of masonry at its ends, the staging below being removed. For the purpose of transporting each tube, eight flat-bottomed floating vessels or pontoons were provided, six of wood and two of iron, the latter being 98 feet long, 25 feet wide, and 11 feet deep, and capable of supporting 400 tons. When bearing the tube, they drew 5 feet of water. In the bottom of each pontoon were large valves, kept open to admit the tide and prevent them from rising. The first operation for floating the tube was to bring these pontoons under it at low water, and to arrange them in two groups of four each, one group near each end of the tube. The valves being then closed, the pontoons rose with the tide and lifted the tube from its bearings. The next operation was to tow and guide this enormous floating body to the exact spot required for depositing it. Calculating that the towing would occupy an hour and a half, it was arranged to start thus much before high water, and with a current of 3 miles an hour. The towing into the middle of the stream was effected by means of large capstans, each worked by 50 men on the opposite shore, the hawsers being made fast to the pontoons at each end. For the purpose of guiding it, two large hawsers were laid down the stream, one on either side, one end being secured to the towers between which the tube was to be raised, and the other to fixed points upon the shore about half a mile from the bridge. These hawsers passed over the pontoons and through fixed sockets in an apparatus called a *cable-stopper*, by which either hawser could be instantly gripped if necessary, so as to stop the motion of the tube. Several smaller ropes were also secured to the pontoons, so arranged as to be taken in or given out by capstans on the shore.

The tube being conveyed to the feet of the towers at high water, the next work was to deposit it on the projecting plinths of the towers which had been prepared for the purpose. This had to be accomplished during the 15 minutes that the tide ceases before the return. Fig. 355 represents the lower part of the Anglesea and Britannia towers A and B, at this period; T is the tube supported upon the eight pontoons and ready to be deposited upon the projecting plinths of the towers. One end of the tube is shown in dotted lines as inserted within the recess left in the Britannia tower, and in the Anglesea tower a portion of the masonry is left out, forming the side of the recess of sufficient height to admit the tube. A sectional plan of the two towers A and B is given in Fig. 356. The former had two recesses on one side for receiving the main tubes, and the latter similar recesses on both sides for the same purpose. One tube T is shown in its place, and the side of the recess at B built up: the other, T′, is still on the pontoons, one end being in the recess of the Britannia tower, and the other end approaching its place in the Anglesea tower, the side of the recess in which, shown in dotted lines, is left unbuilt to receive it. Fig. 357 is a perspective view of the lower part of the Anglesea tower after the raising of one tube and during the raising of the other. It shows the mode of getting the tubes into the recesses by leaving out a portion of the sides at the lower part.

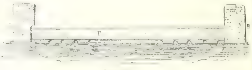


Fig. 355.

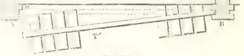


Fig. 356.

The proceedings connected with the floating of one of the main-tubes on the 27th June, 1849, are described by a correspondent of the Illustrated London News. After the preliminary arrangements for letting go had been completed, Mr. Stephenson and other engineers got on the tube, as also Captain Claxton, R. N., to whom the management of the floating was entrusted. "Captain Claxton was easily distinguished by his speaking-trumpet, and there were also men to hold the letters which indicated the different capstans, so that no mistake could occur as to which capstan

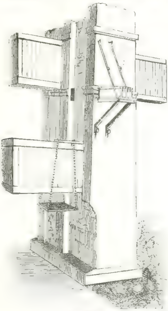


Fig. 357.

should be worked; and flags, red, blue or white, signalled what particular movement should be made with each. About 7.30 P. M. the first perceptible motion, which indicated that the tide was lifting the mass, was observed, and, at Mr. Stephenson's desire, the depth of water was ascertained and the exact time noted. In a few minutes the motion was plainly visible, the tube being fairly moved forward some inches. This moment was one of intense interest; the huge bulk gliding as gently and easily forward as if she had been but a small boat. The spectators seemed spell-bound; for no shouts or exclamations were heard as all watched silently the silent course of the heavily-freighted pontoons. The only sounds heard were the shouts from Captain Claxton, as he gave directions to 'let go ropes,' to 'haul in faster,' &c., and 'broadside on:' the tube floated majestically in the centre of the stream. I then left my station and ran to the entrance of the works, where I got into a boat and bade the men pull out as far as they could into the middle of the straits. This was no easy task, the tide running strong: but it afforded me several splendid views of the floating mass, and one was especially fine: the tube coming direct on down the stream,—the distant hills covered with trees,—two or three small vessels and a steamer, its smoke blending well with the scene,—forming a capital background; whilst on one side, in long-stretching perspective stood the three unfinished tubes, destined ere long to form, with the one then speeding on its journey, one grand and unique roadway. It was impossible to see this imposing sight and not feel its singleness, if we may so speak. Anything so mighty of its kind had never been before: again it would assuredly be; but it was like the first voyage made by the first steam vessel,—something till then unique. At 8.35 the tube was nearing the Anglesea pier, and at this moment the expectation of the spectators was greatly increased, as the tube was so near its destination; and soon all fears were dispelled as the Anglesea end of the tube passed beyond the pier, and then the Britannia pier end neared its appointed spot and was instantly drawn back close to the pier, so as to rest on the bearing intended for it. There was then a pause for a few minutes while waiting for the tide to turn; and when that took place, the huge bulk floated gently into its place on the

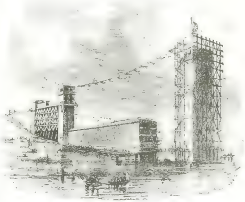


Fig. 358. Floating the main tube.

Anglesea pier, rested on the bearing there, and was instantly made fast so that it could not move again. The cheering, till now subdued, was loud and hearty, and some pieces of cannon on the shore gave token, by their loud booming, that the great task of the day was done." When in its position, the tube was made to settle down upon a bed of timber on its bearings at the foot of the towers, by opening the valves in the pontoons, and thus sinking them sufficiently to free them from the tube.

The tube, having been thus deposited at the bottom of the piers by the buoyant power of water, had to be raised through an elevation of 100 feet over a rapid stream of 460 feet in width, without scaffolding of any kind over the opening. The method proposed for effecting this was by means of hydrostatic presses of great power constructed for the occasion. The enormous force exerted by these presses well fitted them for raising the ponderous mass of 1,800 tons; but the range of the presses was but small, the ram being susceptible of only 6 feet vertical from the cylinder. Hence the tube had to be raised to the required height by a succession of lifts, each of 6 feet, and in order to bring the rams into action, they must either press upwards against the bottom of the tube, or being placed above it, be made to act upon chains, so as to draw them upwards, and with them the tube fixed to their lower ends. The latter course was adopted, and the presses were firmly fixed in the upper part of the towers immediately over the ends of the tube, and at such a height as allowed the tubes to be entirely raised without disturbing the presses. The two presses used for raising the tubes for the Conway bridge, were used in combination at one end for raising the tubes of the Britannia bridge, and at the other end a single press of larger dimensions was employed. The ram of this press was 20 inches in diameter, and the metal of the cylinder 11 inches thick. For the purpose of forcing the water into the cylinders of these presses, two steam engines, each of 40-horse power, were employed. The actual work done by the large press at one end of the tube, or the two smaller ones at the other, is of course equal to raising half of the tube, or 900 tons: hence the power exerted by the head of the ram 20 inches in diameter, is equal to 2.25 tons or 5,040 lbs. per circular inch.

During the lifting of the first of the Britannia tubes on the 17th August, 1849, after three of the 6-feet lifts had been successfully accomplished on previous days, the lifting was proceeding and $2\frac{1}{3}$ feet was attained, when the bottom of the cylinder of the large press burst out, and fell with terrible force (its weight being about $1\frac{1}{2}$ ton) on the top of the tube below, a depth of 70 or 80 feet, producing a deep indentation, and unfortunately striking fatally a poor sailor employed on the works, who at the time was ascending a rope ladder from the tube to the press. The resistance to the weight being thus suddenly destroyed, the ram of course descended the part of the lift accomplished, and the tube would also have fallen through a similar space of $2\frac{1}{3}$ feet, had not Mr. Stephenson adopted the wise precaution of following up the ascending tube with packings of wood 1 inch thick, which were introduced within the recess as quickly as the tube rose. This accident will sufficiently account for the considerable delay in raising the tube.

At the meeting of the British Association for the Advancement of Science, held at Birmingham in September 1849, Mr. Stephenson explained the cause of the accident. He stated that the plan originally proposed, was by lifting the tube to the height of 6 feet at a time, and then allowing it to be suspended by chains to the cross head during the time the masonry below was carried up: but this plan was abandoned, fearing that if an accident should take place either by the bursting of the press or the breaking of a link of the chain, the tube would be totally destroyed if it fell through such a height as 6 feet or even 6 inches. He considered that the only way to proceed was by packing in timbers inch by inch under the tube as it was being lifted, so that in case an accident did take place, the tube would not have to fall through a greater space than an inch, and this was the plan adopted at the time of the accident. To show how necessary this was, it was stated that although the tube fell through the space of only 1 inch, it broke down iron beams, each sufficient to bear 500 tons weight. As a further precaution, it was intended to pack in under the cross-head of the press, by driving in iron wedges as the tube was raised, so that if the press were to break down, neither the cross-head nor the tube could fall through a greater space than an inch. The nature of the fracture will be seen from Fig. 359, and it is curious to find that the fracture took place at that part of the press which was the strongest, for it broke through the angle of the bottom at F, and when it fell out, the piece formed the frustum of a cone. At the time the presses were at work, there was not 1 ton pressure to the square inch, the area of the fracture being 1,316 square inches, and the weight suspended on the press 1,000 tons. The press was calculated to bear $3\frac{1}{4}$ tons, a pressure to which hydraulic presses are frequently subjected for manufacturing purposes. The ram at the time of the accident dropped $2\frac{1}{3}$ feet: if it had been wedged up as now proposed, the accident might not have occurred. Mr. Stephenson believed the fracture took place in consequence of the unequal cooling of the iron at the angle F; he had therefore decided upon having two cylinders cast in some other form, one as in Fig. 360 with a spherical bottom, the same thickness as the cylindrical part; and the other as in Fig. 361, with an open bottom and a plate made to close the opening. It was also stated that when lifting the Conway tubes, they commenced by lifting both ends simultaneously; but when the engines had been at work for a short period, the tube was observed in a tremulous motion like a wave. By working the pumps at each end alternately, the motion was got rid of. Some distinguished mechanical philosophers present at the meeting, considered that the accident at the Britannia bridge might have been occasioned through pulsation of the press, arising from the oscillating motion, however small, of the tube.[1]

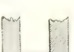


Fig. 359

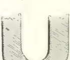


Fig. 360

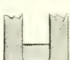


Fig. 361

A perspective view of the Anglesea tower is given in Fig. 357, showing one of the tubes elevated to its place, and another tube partly raised. It also shows the three cast-iron key-beams drawn out and supported on a bracket platform. When the tube was lifted to its full height, these beams were driven into their permanent places in the boxes which were built into the towers, and thus served to support the ends of the tube while the chains and lifting frames were detached. The rising tube had also a stage slung upon it, upon which the workmen were supported for the purpose of packing the wooden slabs under the tube as it rose, and building up the recess with brick-work in cement.

Figs. 362 and 363 show the combined arrangements for lifting the tubes of the Conway Bridge, with the hydraulic press, chains, &c. and the cast-iron lifting frames, as described in Mr. Fairbairn's work. Fig. 362 is a transverse section through the tube and front

[1] Civil Engineer and Architect's Journal for October 1849.

elevation of the press. Fig. 363 is a side view of the end of the tube, together with the press. In the sectional view it will be observed that the press H had to be supported upon 4 large cast-iron beams A 1, A 2. The two principal beams marked A, were 4 feet deep, and calculated together to support a load of 1,400 tons in the middle, or 2,800 tons when distributed over their surface. To effect that distribution, and to make allowance for any unforeseen defect in the castings, two other beams, A 2, A 2, each 24 feet long, were laid upon the top of the beams A, and by means of a lining of soft wood between them, an equal distribution of load was obtained. On the top of the ram B was placed the cross-head C, having a perfectly flat surface on the top side, and two rectangular openings at each end to admit the chains T T passing through as shown at *a*, Fig. 362; also two circular holes at *b*, *b*, running upon the slide bars *c c* which were attached to the cross-beam D to keep them steady. To each end of the tube three strong cast-iron frames E E E were riveted, and to these again were fitted the trans-

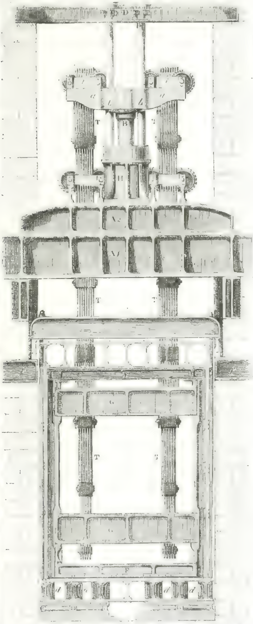


Fig. 362.

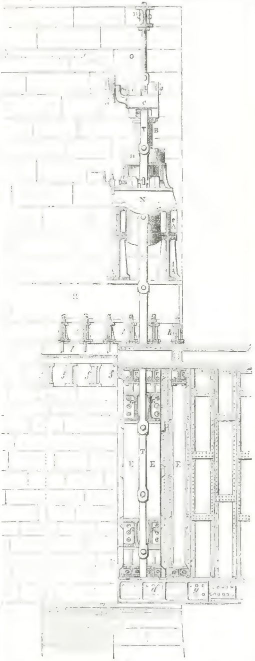


Fig. 363.

verse beams F F F, &c., collectively forming three strong frames, of the height, width and interior dimensions of the end of the tube. The object of these frames was to stiffen the sides, top and bottom of the tube, and to connect them with each other at the point where it rested on the piers, and had to sustain a pressure of from 600 to 700 tons. These frames had also to receive the cross beams G G, to which the chains for raising the tubes were attached. These latter beams were computed to sustain a load of 3,000 tons and upwards, and the more effectually to equalize the pressure upon them, wrought-iron keys were inserted between the cross-beams and the shoulders of the side frames E E, which also had the effect of regulating and rendering uniform the tension of the chains. In this way a power was obtained of giving to each beam its equivalent share of the load.

The reasons for giving rigidity to each end of the tube were, 1st, to strengthen the sides at those parts, and to protect the upper and lower cells from injury; 2dly, to strengthen the lower cells and render them capable of sustaining the weight of the tube when resting wholly on its base; and 3dly, to make the whole of these parts of sufficient strength to resist the strain, whether arising from a vertical pressure upon the bottom, or from a tensile strain when suspended by the chains and hydraulic pumps. To attain these objects the strong cast-iron frames E E, &c., were inserted, which acted alike as pillars and suspenders, and the cross beams F F, &c., which distributed the pressure along the under and upper surface of the cells, thereby equalizing the strain in almost every direction over the interior as well as the exterior portion of that part of the tube.

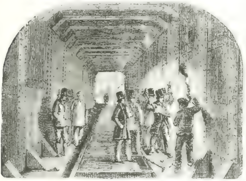
The cast-iron frames *d, d, d*, &c., which embrace the vertical divisions of the lower cells, extend to a distance of 4 feet beyond the bearing of the tube, where they terminate on the sides of the plates, with a thin edge like a wedge, as at *g*, Fig. 363. By this arrangement a strong and perfectly rigid basement was introduced at the points of greatest pressure, without obstructing the entrance into the cells, or in any way impairing the efficiency of the tubes. In the upper cells, which are not subject to pressure, the same precautions were not required, since it was found that the top cross frames F were amply sufficient to protect these cells from injury during the process of lifting.

In addition to the two large beams A 1 and A 2 for supporting the hydraulic press, two strong beams R were built in the side walls, on each side of the recess, to prevent the unusual strain of such an enormous weight fracturing the masonry and sliding off in the shape of a wedge. Besides these beams, six other transverse beams were inserted at *f f*, &c., carrying the cast-iron troughs *l l*, &c. which held the gun-metal balls on which the upper part of the tube was supported. On the back or top of the upper troughs rested the ends of six strong cast-iron beams *h h*, &c. These beams crossed each end of the tube at a distance of 3 inches from the top, and by means of an equal number of screw-bolts riveted to the sides of the tube, the required weight could be thrown upon the balls. Thus the tube was not only supported by the top as well as the bottom, but one half of the weight resting upon the balls gave additional security to the vertical position of the tube when advancing to or retiring from the towers by the expansion or contraction of the metal. At the other end, which was stationary, the same principle of support was employed, except that the balls and rollers were not required. The bottom of the plate at the movable end was supported on the bed-plates *m m*, and between them were two frames containing drilled rollers, Fig. 354, on which the top plate, and along with it the tube, moved with the same facility as on the balls above.

The lifting chains T, T, were formed in links with notches at one end of each alternate link, fitting into corresponding ones on the lower flanges of the cross girders G, G, and when these were bolted in their places, the links were as shown in Fig. 362, held firmly between them. Each set of links consisted of 8 and 9 alternately, the 8 being made somewhat thicker than the 9, so as to be equally strong. Each link was 7 inches wide, and about 1 inch thick, and exactly 6 feet in length between the centres of the eyes at the ends, their length being thus adjusted to the stroke of the ram of the press. They were manufactured by Howard's patent process, by which wrought-iron bars are rolled with the ends or heads of increased breadth in one entire piece, thereby getting rid of the uncertain process of welding.

The press by which these chains were drawn up, and the tube thereby raised, is shown in the place above the tube which it occupied during the whole operation. The press consists principally of the cylinder H, the ram or piston B, a pipe by which the water was introduced from the pumps, and the cross-head C. The cylinder rested within a cast-iron jacket or casing, supported upon the transverse girders A 1 A 2. The forcing of water into the cylinder causes the ram to rise, forcing up with it the cross-head C. Upon the cross-head two pairs of clamps, *i i*, were fixed, which embraced the notched ends of the chain links and were screwed up tightly against them with screws. These screws had cogged wheels *k* fitted to their ends, and an intermediate pinion, turned by a winch, gave motion to the wheels of the two screws. A similar arrangement of clamps and gearing was fixed below. The action of the press was preserved in a truly vertical direction by fixed guide rods, *c c*, secured above to the cross-girder D, and upon these rods the cross-head slid upward as the action of the press continued. The apparatus by which the tubes were sustained during the time of lowering the ram for the succeeding lift, consisted of two distinct sets of clips, one for embracing the links upon the cross-head of the ram during the time of lifting, as shown at C, and the other for supporting the weight of the tube on the frame N until the ram and cross-head were lowered to a position for seizing the next link. These changes were effected by the simple process of screwing the clips which slide upon the cross-head c, close upon the chains, when the tube had to be raised; and by a similar movement of the clips which slide upon the frames N they were drawn under the shoulders of the links, and by this means the tube was held suspended until the clips on the cross-head were opened and the ram lowered for the succeeding lift. This was done by the wheels and pinions *kk*, which opened or closed the clips by right and left-hand screws, which, working in brass nuts, were attached to each block. The top links at o were dragged forward along the top of the tower during the ascent of the tube without disjointing the links.

In concluding this notice of the Britannia Tubular Bridge, it should be stated that the masonry of the Central or Britannia Tower was commenced in May, 1846; that the first rivet for the tubes was put in on the 10th August, 1847, and the last of the tubes was safely lowered to its permanent resting place on Friday, the 2d September, 1850. The Caernarvonshire end of the tube was lowered three feet, the opposite end being joined on to the Anglesea large tube in the interior of the tower on the Britannia rock, and, obedient to the law of the novel operation, the centres of both tubes, as before, were raised up several inches. Nothing beyond a mere fractional deflection has been observed to take place in the tube that has been opened since March, and which has been subjected to the constant transit of heavy trains and traffic. Some curious acoustic effects have been observed. Pistol shots, or any sonorous noises, are echoed within the tube half-a-dozen times. The cells of the top and bottom are used by the engineers as speaking tubes, and they can carry on conversations through them in whispers; by elevating the voice, persons may converse through the length of the bridge—nearly a quarter of a mile. On Monday, 21st October, 1850, the permanent public opening of the new line of tubes for the down line, from London to Dublin, took place; the great structure being in all important respects completed. On the 19th October, the Government inspector went over it, and instituted, in conjunction with the engineers, a long series of experiments. The first experiment consisted in passing two locomotive engines through the tube, and resting them at intervals in the centre of the sections. A train of 28 waggons and 2 locomotives, with 280 tons of coal, was drawn into all four of the tubes, the deflections being carefully noted. These deflections were ascertained to be exactly three-quarters of an inch under this load. After repetitions of these experimental ordeals, which occupied several hours, the train of 280 tons, with its two locomotives, was removed about a mile distant from the tube, and then suddenly shot through it with the greatest attainable velocity; and the result was, that the deflection at this immense velocity of load was sensibly less, in the way of undulation, than when the load was allowed to remain at rest in the tube. The contrivance by which the effects are indicated, with great precision, consists of a large pipe containing water, laid along the lower cells of the tube, one end rising up within the tube at the centre, and the other end fixed against the stonework of the abutment of the bridge. Both extremities of the pipe are furnished with glass tubes and graduated scales, by which the relative levels of the water can be easily ascertained. As the slightest leakage or evaporation, over the ordinary thermometric expansion of the water, would derange the level, while only half the actual deflection of the tube was registered at each end of the pipe, these disadvantages are obviated by the addition of a large reservoir of water in the centre of the tube, which is covered with oil, and placed beside the graduated scale. This larger area exhibited the whole of the deflections at the abutment extremity, and the apparatus presents a perfect representation of all the deflections and phases of the great structure. Messrs. E. and L. Clark, the resident engineers, who have watched minutely from day to day all the developed peculiarities of the novel undertaking, state that the heaviest gales through the straits do not produce so much motion over the extent of either tube as the pressure against the side of the tubes of ten men; and that the pressure of ten men, keeping time with the vibrations, produces an oscillation of 1¼ inch; the tube itself making 67 double vibrations per minute. The strongest gusts of wind that have swept up the channel during the late stormy weather do not cause a vibration of more than ¼ inch. The broadside of a storm causes an oscillation of less than an inch; but when the two tubes are braced together by frames, which is now being done, these motions, it is expected, will cease. The action of the sun at midday does not move them more than ¼ or ⅜ths of an inch. The daily expansion and contraction of the tubes varies from half-an-inch to three inches, attaining either the maximum or minimum at about 3 o'clock A.M. and P.M. If a compass be held over any part of the bottom of the cells, the south pole is affected, and if held over the top of the cells, the north pole is affected; and this effect is observable in all parts of the tube, whether at the centre or the end, although their position is only about 10° west of the magnetic meridian. Preparations are making for covering the tubes with a light arched roof, of peculiar construction.



[illegible]

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(1) For this figure, as well as Figs. 243, [illegible], we are indebted to the *Illustrated London News*.

The following is an official return of the cost of the entire structure:—

Pedestals and abutments on Carnarvon side	£ [illegible]
Caernarvon tower	[illegible]
Britannia tower	[illegible]
Anglesea tower	[illegible]
Pedestals and abutments on Anglesea side	[illegible]
Lions	[illegible]
Total for Masonry	[illegible]
Wrought iron used in tubes	[illegible]
Cast iron in tubes and towers	[illegible]
Construction of tubes	[illegible]
Pontoons, ropes, capstans, painting materials, &c.	[illegible]
Raising machinery	9,782
Carpentry and labour in floating, raising, &c., complete the bridge	[illegible]
Experiments	[illegible]
Total	£[illegible]

The entire bridge, including both lines, contains nearly a million and a half cubic feet, or 105,000 tons, of masonry, 44,200 cubic feet, or 9,480 tons, of wrought-iron, and 1,988 tons of cast-iron. The two tubes, in their complete state, contain 9,360 tons of wrought-iron, 1,015 tons of cast-iron, and 165 tons of permanent way. They are composed of about 186,000 separate pieces of iron, pierced by seven millions of holes, and united by upwards of two millions of rivets. They contain 435,700 feet or 83 miles, of angle-iron; and their total weight is 10,540 tons.

BRIMSTONE, (from the Saxon *Brenne-stone*, a stone that burns) See SULPHUR.

BRINE-WELLS, see SODIUM, chloride of.

BROMINE, (from βρῶμος, a noisome smell,) an elementary substance, discovered in 1826 by M. Balard, of Montpellier, in the bittern, or uncrystallizeable residue of sea-water. It is contained in minute quantities in sea-water, and is a frequent constituent of saline springs, chiefly as bromide of magnesium. There is a celebrated spring of this kind near Kreutznach, in Prussia, which is the chief source of bromine as an article of commerce.

At common temperatures, bromine is a red thin liquid, of an exceedingly intense colour, very volatile, and of a very suffocating and offensive odour. Phosphorus ignites spontaneously in its vapour: tin and antimony also burn in it. Bromine becomes solid and crystalline at 9°·5, and boils at 145°·4. The density of the liquid at 32° is 3·187, and of the vapour 5·39. Bromine is fatal to animal life. It is slightly soluble in water, more freely in alcohol, and most abundantly in ether. The aqueous solution destroys vegetable colours. Bromine forms hydrobromic acid with hydrogen, and bromic acid with oxygen. Its symbol is Br, and equivalent 80.

BRONZE is an alloy of copper and tin, used by the ancients for casting statues and other ornaments. In the following table, the composition of several ancient bronzes is given, showing the number of ounces of tin added to each pound of copper.

¾ oz. Ancient bronze nails, ductile; or, 20 copper, 1 tin.

1¼ oz. Soft bronze; or 9 to 1.

2 oz. Medium bronze; or 8 to 1.

2¼ oz. Hard bronze; or 7 to 1.

6 to 8 oz. Ancient mirrors.

According to various modern analyses, ancient weapons and tools contained from 8 to 15 per cent. of tin; medals, from 8 to 12 per cent. tin, with 2 parts zinc added to each 100, for improving the bronze colour.

The modern alloys of copper and tin have led to the production of a variety of metals, bearing different names, and applied to different uses. The principal of those which have as yet been discovered are—

1 oz. Soft gun-metal, that bears drifting, or stretching from a perforation.

1⅓ oz. A little harder, fit for mathematical instruments; or, 12 copper, and 1 very pure grain tin.

1½ oz. Still harder, and fit for wheels to be cut with teeth.

1½ to 2 oz. Brass ordnance; or, 8 to 12 per cent. tin. The general proportion is one ninth-part of tin.

2 oz. Hard bearings for machinery.

2½ oz. Very hard ditto.

3 oz. Soft musical bells.

3½ oz. Chinese gongs, and cymbals; or, 20 per cent. tin. This alloy, when newly cast, is very brittle; but, by being plunged at a cherry-red heat into cold water, and confined between two discs of iron, to keep it in shape, it becomes tough and malleable.

4 oz. House-bells.

4½ oz. Large bells.

5 oz. Largest bells.

7¼ to 8¼ oz. Speculum metal. In some cases, 1 oz. of brass is added to each pound, for the purpose of introducing a small portion of zinc. In other cases small proportions of silver or arsenic are added. The Earl of Rosse says:—"Tin and copper, the materials employed by Newton in the first reflecting telescope, are preferable to any other with which I am acquainted; the best proportions being 4 atoms of copper to 1 of tin; in fact, 126.4 parts of copper to 58.9 of tin." The object appears to be the exact saturation of the copper with the tin; but in this, as in every other alloy, the proportions differ with the degrees of purity of the metals. "When the alloy is perfect, it should be white, glassy, and flaky. When the copper is in excess, it imparts a red tint, easily detected; when the tin is in excess, the fracture is granulated, and also less white." The melted tin should be poured into the fluid copper at the lowest temperature that a mixture can be produced by stirring. The mixture is then poured into an ingot, and the combination completed by gradually remelting, putting the metal into the furnace almost as soon as it is lighted. Trial is made of a small piece taken from the pot before pouring.

32 oz. of tin to 1 lb. of copper make an alloy called by pewterers *temper*, which is added in small quantities to tin for some kinds of pewter, called *tin and temper*, in which the copper is often less than 1 per cent, [See PEWTER.]

The addition of tin continually increases the fusibility of the alloy, although, when added cold, it is apt to make the copper pasty, or even to set it in a solid lump in the crucible. In the proportion of 2½ oz. to the pound, the tin does not greatly impair the red colour of the copper. It becomes greyish white at 6, and quite white at 8. Beyond this the alloy has a bluish cast. The alloy is scarcely malleable at 2 oz., and it soon becomes hard, brittle, and sonorous. Alloys of 1½ cut easily; at 2½ they are at the hardest, without being crystalline; beyond this they crumble under the file, until the tin is greatly in excess, as in the pewters, when the alloys become flexible, soft, malleable, and ductile, the less the proportion of copper.

In some bronzes small proportions of zinc and lead are added. For gilt ornaments of bronze it has been recommended to employ 82 parts copper, 18 zinc, from 3 to 1 of tin, and from 3 to 1½ of lead. Such an alloy has a close grain; but the lead diminishes the tenacity, and increases the density. Another alloy, which is said to require only a small quantity of gold in the gilding, is composed of copper 82.257, zinc 17.481, tin 0.238, lead 0.024.

The antique bronze colour is given to bronze figures by the following process:—Two drachms of sal-ammoniac and half a drachm of binoxalate of potash are to be dissolved in 14 ounce-measures of colourless vinegar. This solution is to be applied with a hair-pencil in a very thin layer, the object having been previously warmed gently; and the operation is to be repeated until the desired colour is produced.

For the casting of bronze statues, &c., see CASTING.

A cheap method of forming articles in bronze, by the electrotype process, has recently been introduced. In 1841, M. de Ruolz communicated to the Academy of Sciences at Paris a process by which he bronzed metals, by depositing on them, by means of the voltaic battery, coatings of brass or bronze, of variable thickness. This process required the use of the double alkaline cyanides of copper and zinc, or copper and tin, the high price of which precluded their use in practice. Instead of these cyanides, MM. Brunel, Bisson and Gaugain employ an aqueous solution of 500 parts carbonate of potash, 20 parts chloride of copper, 40 parts sulphate of zinc, 250 parts nitrate of ammonia. In order to obtain bronze, a salt of tin is substituted for the zinc. By means of these solutions, wrought or cast-iron, steel, lead, zinc, tin, and the alloys of these metals, either with each other or with bismuth and antimony, may readily be coated with brass or bronze, after being properly cleaned or scoured, according to the nature of the metal. The operation is performed at the ordinary temperature. The article to be coated is put in communication with the negative pole of a Bunsen battery; the positive decomposing pole being a plate of brass or bronze. When large surfaces are to be coated, the number of pairs of plates, not their size, must be increased. When the articles have been coated, and coloured in the usual way, they are equal in beauty to the finest bronzes. Rough cast-iron may by these means be made to assume a very beautiful appearance; and articles thus coated will be preserved from rust in-doors; but if intended for the open air, they must be protected by a suitable varnish. In 1847, a patent founded on this method was granted to C. de la Salzede. [See ALLOY, App.]

BRONZING is the art of communicating to articles in metal, wood, ivory, clay, or plaster, the effect of bronze statues. An important ingredient in bronzing is *gold-powder*, which is prepared in the following manner. Leaf-gold is ground with virgin honey on a stone, until the leaves are broken up and minutely divided. The mixture is then removed from the stone by a spatula, and stirred up in a basin of water, whereby the honey is melted, and the gold set free. The basin is then left undisturbed until the gold subsides. The water is then poured off, and fresh quantities added, until the honey is entirely washed away; after which the gold is collected on filtering-paper and dried for use. An inferior powder, called *German gold*, is prepared in a similar manner. There is also a third, which is in very common use, called *aurum musivum*, or *mosaic gold*, and is prepared in the following manner:—A pound of tin, 7 oz. of flowers of sulphur, half a pound of pure mercury, and half a pound of sal-ammoniac are the ingredients. The tin is melted in a crucible, and poured into the mercury: when this amalgam is cold, it is reduced to powder, and ground with the sal-ammoniac and sulphur until the ingredients be well incorporated. They are then calcined in a matrass, and the sublimation of the other ingredients will leave the tin in the state of aurum mosaicum at the bottom of the glass, in the form of a bright flaky gold powder. Any black or discoloured particles must be removed. These powders are commonly used in bronzing; but when a shade of red is required, to resemble copper, it can be given by grinding a very small portion of red-lead with the ingredients. *Copper-powder* is prepared by dissolving filings or strips of copper with nitrous acid in a glass flask. When the acid is saturated, the slips are removed, or the solution is poured off from the filings. Small iron bars are then put in, which will precipitate the copper from the saturated acid in the form of a powder resembling copper. The liquid is then to be poured off, and the powder washed repeatedly with water. *Gold-size*, also used in bronzing, is prepared from a pound of linseed oil, with 1 oz. of gum animi. The latter is reduced to powder, and gradually added to the oil while being heated in a flask, stirring it after every addition, until the whole is dissolved. The mixture is boiled until a small quantity, when taken out, is somewhat thicker than tar, and the whole is strained through a coarse cloth. When used, it must be ground with as much vermilion as will render it opaque, and at the same time be diluted with oil of turpentine, so as to make it work freely with the pencil.

In bronzing plaster figures, a cement may be used or not; but if used, the bronzing will be more durable. If a cement be used, the powders are mixed with strong gum-water or isinglass, and laid on with a pencil or brush. Some artists begin from the bottom, and work upwards. The subject to be bronzed may also be covered with gold-size, diluted with turpentine, and being allowed to dry very nearly, a piece of soft leather, wrapped round the finger, is dipped into the powder, and rubbed over the work, or the powder may be spread with a soft camel's-hair pencil. When the whole is covered, it is left to dry, and the loose powder is then cleaned off with a hair pencil. Much of the effect depends on applying the powder at the proper point of dryness. The precise tint, and the proper distribution of light and shade, must be left to the taste of the artist.

For bronzing on wood, prussian blue, patent yellow, raw umber, lamp-black, and pipe-clay, are separately ground with water on a stone, and as much of them as will make a good colour is put into a small vessel containing sufficient size to produce not quite that strength called *clean size* in gilding. The wood having been cleaned and smoothed, is coated with a mixture of clean size and lamp-black: it is then coated twice with the above ingredients, drying between each application. The bronze powder is then applied with a pencil, and the whole is burnished or cleaned. The parts injured by this process having been repaired, the work is coated with a thin lather of Castile soap, which will take off the glare of the burnishing: it is then carefully rubbed with a woollen cloth. The gangrenous appearance of the cavities is produced by wetting them slightly with a hair-pencil dipped in the lather, and then sprinkling them with a little dust of verditer gum. When dry, the superfluous powder may be rubbed off.

Copper-coins and medals may be bronzed by the following process.—Dissolve in vinegar 2 parts verdigris and 1 part sal-ammoniac. Boil, skim, and dilute the solution with water until it ceases to let fall a white precipitate. The solution is then made to boil briskly, and is poured upon the objects to be bronzed, previously made perfectly clean and free from grease, and set in a copper pan, which is to be put on the fire and the boiling renewed. The pieces must be so arranged that the solution may be in contact with every point of their surface. The copper thus acquires an agreeable reddish-brown hue without losing its lustre, but it is necessary to inspect the articles every five minutes and to remove them from the solution the moment the desired shade is attained. The pieces must then be washed repeatedly with water and carefully dried. If the solution has been too strong, the bronzing will come off with friction, or turn green by exposure to the air.

An antique bronze appearance may be given by dissolving 1 part sal-ammoniac, 3 parts cream of tartar, and 6 parts common salt, in 12 parts of hot water. This solution is to be mixed with 8 parts of a solution of nitrate of copper, specific gravity 1.160. When this compound is applied repeatedly, in a moderately damp place, to articles of bronze, it gives them a durable green coat which gradually increases in beauty. By increasing the proportion of common salt, a yellowish tinge is produced; by diminishing it, a bluish cast is obtained. A large addition of sal-ammoniac hastens the process.

The browning or bronzing of gun-barrels and other articles of iron consists in giving them a shining brown colour, which improves the appearance, protects them from rust, and in the case of gun-barrels serves to conceal them from the game and the enemy.

By one operation a thin uniform film of oxide of iron is raised on the surface, and the gloss is given by rubbing wax over it or coating it with shell-lac varnish. The film of oxide is produced by exposing the iron in a close place to the vapour of muriatic acid, or by moistening the surface with dilute muriatic or nitric acid. Butter or chloride of antimony, called *bronzing salt*, is commonly used. It is mixed with olive oil, and rubbed upon the iron slightly heated. A greater or less exposure to the air produces the desired degree of browning. The operation is quickened by rubbing in a little nitric acid after the antimony has been applied. The barrel is then carefully cleaned, washed with water, dried and polished either by a steel burnisher, or rubbed with white wax, or varnished with a solution of 2 oz. of shell-lac and 3 drachms of dragon's blood in 2 quarts of spirit of wine.

The finest kind of browning is the Damascus, in which dark and bright lines run through the brown ground. To produce this, the barrel is rubbed over with very dilute aquafortis and vinegar, mixed with a solution of sulphate of copper. It is then washed and dried and rubbed with a hard brush to remove any scales of copper.

The reader interested in the subject of Bronzing will find a vast number of recipes scattered through different works on Metallurgy and the Fine Arts, &c. He must be cautious in compounding the ingredients, for some of the mixtures throw off fumes which are dangerous if inhaled, and others will corrode ordinary vessels. Indeed, it is generally dangerous for an amateur to concoct the recipes which he finds in books unless he be a tolerable chemist.

BRUSH. An assemblage of hairs, hogs' bristles, strips of whalebone, vegetable filaments, &c., fastened together in a handle, or in holes drilled for the purpose in a stock of wood or bone. Brushes may be round, flat, or square; and they are named according to the uses to which they are applied. The smallest kind of brush, such as is used in water-colour drawing, is called a *hair pencil*, and the hair employed may be that of the camel, the badger, the squirrel, the goat, and some other animals. Hair pencils are made by collecting a small tuft or bundle of hairs, with the points all in one direction, and binding the root ends firmly together with strong thread. The points being temporarily secured, the tuft is put into the wide end of a piece of quill tube, previously softened and made pliable by wetting, and is passed down the tube until the points project at the small end, the superior thickness of the roots and the binding-thread preventing the tuft from passing completely through; and the tube, in drying, contracts, and holds the tuft securely. The broad end of the quill forms a socket for the reception of a stick of cedar-wood. Some care is required in making hair pencils, for if the tuft be not properly put together, or if pinched too tightly, either by the thread or by the contraction of the quill, the hairs will spread out instead of forming a fine point, which they ought to do when wetted. Hair pencils are made of various sizes, from that of a small crow or pigeon quill to the largest goose, turkey, or swan quill; and when larger than these are required, tin-plate tubes are used, with the handle or stick firmly secured therein. The ancients had pencils made of small pieces of sponge, whence the story of the painter who, not being able to express the foam of a horse, succeeded by throwing "the sponge" at the picture.

Bristles, however, form by far the chief article in the manufacture of brushes; and the consumption is so vast as to give rise to a very important commerce in this article. They form the strong glossy hairs growing on the back of the hog and wild boar. Russia is the great mart for bristles, those of the Ukraine being most esteemed. The total quantities of bristles imported into the United Kingdom during the years 1858, 1859, and 1860 were, 2,055,596 lbs., 2,195,932 lbs., and 2,534,207 lbs. respectively. The great bulk is furnished by Russia; Prussia (Königsberg) supplies about 130,000 lbs., and other parts of Germany a similar quantity. The duty, which varied from 2*s*. 6*d*. on rough to 3*s*. per cwt. on sorted bristles, produced, in 1842, 24,100*l*. 17*s*. 11*d*. nett. Bristles have been free of duty ever since the 19th March, 1845, in which year the number of pounds imported amounted to 2,412,267.

A considerable quantity of bristles is also imported from France. These are of various colours; but that which is called the *lily*, on account of its silvery white appearance, is most esteemed. It is used chiefly for shaving-brushes, tooth-brushes, and the softer descriptions of hair-brushes. The thickest bristles are the most valuable, and the price diminishes with their size.

Bristles, as taken from the animal, are of various colours intermixed; but, before being used, and sometimes before being imported, they are sorted by hand into *black*, *grey*, *yellow*, *white*, and *lilies*, the last variety being the lightest. A bundle of any of the other varieties generally contains many shades of colour, which are carefully intermixed when it is intended to use them together. The bristles being sorted into different colours, they are next sorted into different sizes by a process called *dressing;* for which purpose a number of combs, called *engines*, Figs. 365, 366, formed by thrusting the heads of needles, of various sizes, and at various distances apart, into blocks of wood, are set up on a bench before the workmen, six or eight of these combs being commonly used. He then takes a bundle of bristles, weighing from $\frac{3}{4}$ lb. to 4 lbs., and opening the bundle, strikes the bristles upon the first or widest comb, and draws them through. By repeating this operation several times the largest and stoutest bristles are retained between the teeth of the first comb. He then passes on to the second comb, which, in like manner, retains those bristles which are a little smaller than the first; and in this way he proceeds until the whole bundle is separated into as many degrees of fineness as there are combs. The dressed hairs are, for the finest work, again picked, and all the different shades of colour collected into separate heaps, care being taken in all these operations to keep the root ends together.

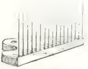
Fig. 365.

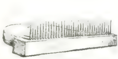
Fig. 366.

The simplest form of brush is that denominated a *tool*. It is of various sizes and forms, the cylindrical and the flat being most common. In the larger bristle-tools, used in house-painting, the bristles are taken of the whole length, and are tied firmly to the end of a wooden stick or handle, cut into a forked shape. The bundle of bristles being inserted between the two projecting prongs, is secured by twine, and the twine is protected by a coating of glue, mixed with red lead, to render it less soluble. In another kind of brush, the handle, instead of containing the tuft, as in the above example, is inserted into the tuft, as in the large painting and dusting brushes, used by house-painters. The bristles are first wrapped round the smaller end of the conical wooden handle, and, being properly secured, are placed in a thin hollow iron block, perforated in the centre for the handle to pass through, and forming around this hole a sort of cup for the bristles: the handle is then driven in with considerable force, so that the thick end is held firmly in the centre, as a sort of core, and, by pressing the bristles tightly against the side of the iron, holds them securely.

Stock-brushes, used as whitewash and distemper brushes, consist of two or more cylindrical brushes, placed side by side, and fastened separately upon the edge of a flat stock or handle, each brush being divided into two semi-cylindrical portions by the thin edge of the stock between them.

The commonest form of brush or hair-broom[1] is formed by the insertion of a number of tufts or knots of bristles into holes drilled in a stock of wood. There are two methods of doing this, the first and simplest of which applies chiefly to the making of brooms. The heads or stocks are bored to a sufficient depth by means of the boring bit and brace, and where the bristles are intended to spread out obliquely, the holes are bored to the proper angle. In many cases, however, the stock is formed with a curved face, so as to give the proper spread or *splay* to the brush. The tufts are inserted by what is called *pan* or *set-work*. Three or four men, seated round a small charcoal stove, containing a pan, about three inches deep, of melted pitch, Fig. 367, proceed in the following manner. Each man takes up a number of bristles sufficient for one knot, and strikes the ends on a board or smooth stone until they are even and regular; then, holding them tightly near the ends which are to be inserted, he dips these ends into the pitch, and, taking them out, scrapes them against one of the edges of metal seen in the pan, by which means he removes the superfluous pitch, and drives a portion of it into the interior of the mass. He next quickly takes a *thread* of string, a few inches long, and winds it round the pitched ends of the bristles, Fig. 368, dips it again into the pitch, and immediately inserts it into the hole in the stock, Fig. 369, with a twisting sort of motion. The pitch almost immediately sets, and holds the knot so securely that it is impossible to pull it out by hand. Long brooms, bannister-brushes, hearth-brushes, dusting-brushes, (technically called *set dusters*, to distinguish them from painters' dusters,) are made by this process, the bristles being commonly of the whole length. In Thomason's iron constat hearth-brush, the bristles are concealed in a case, and, by the action of pulling on a tube, the bristles are protruded; the object being to conceal them from the eye when the brush is not in use. The handle and tube are made ornamental, and the bristles, being out of sight, do not offend the eye, nor soil the wall near which they are hanging.

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[1] *Broom* is so called from its having been originally made of the small branches of the plant of that name. *Brush* is supposed to be so called because it is made of *bristles* or *brustles*. Skinner suggests that *bristle* is from the verb to *burst* or *brust*, because the bristle *bursts* through the skin.

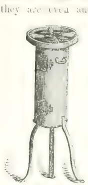


Fig. 367.

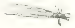


Fig. 368.

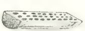


Fig. 369.

Brushes used for laying on colour, for dusting or sweeping, require much less force than those used in the operations of *brushing*, as the term is commonly understood. The increased hardness or stiffness of a brush is obtained by folding up each tuft of bristles, so that each bristle may present its two ends upwards; and these being cut square and even, a hard surface is presented, especially when this doubling is performed near the root ends, which are much stronger and more durable than the *flag* or taper ends of the bristles.

The stocks, or brush-boards, are made of almost every description of wood; birch, beech, oak, and chestnut being most common; while for the best brushes satin and rose-wood are used. These boards are supplied by the timber merchant of the requisite thickness either for drilling or for veneering. The boards are economically cut, as in Fig. 370, so as to get two brushes out of each board. The drilling is performed in a small lathe, in which the drill projects in a direct line from the operator, as in Fig. 371; and, in order to bore the holes correctly, a *scale*, or pattern-board, ready drilled, (thousands of these scales being kept on hand,) is attached by clamps to the board which is to be drilled. All, therefore, that the man has to do, is to pass the drill through the holes of the pattern into the board attached to it. If the board have bevelled edges, in which the bristles are inserted in an oblique position, a leaden pattern or scale is used: this can be bent to any degree of *spread* that may be required. In some cases, the holes are drilled not entirely through the board, but only as far as the tuft is intended to go; after which, a small tool, called a *bore-through-bit*, is fixed in the lathe, and with this smaller holes are drilled through the stock, in continuation of the larger holes. After the drilling, the boards are cleaned off with a plane, to make the holes smooth, and in some kinds of brush the face is French-polished.

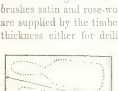


Fig. 370.

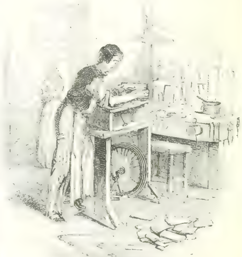


Fig. 371. DRILLING THE BRUSH BOARDS.

Then comes the operation of *drawing*, which employs by far the larger number of hands in the trade. This is generally done by females, who are seated round a table, each with a lapful of bristles (Fig. 372). Each woman places a drilled stock in a holdfast secured to the table, and passing the loop or bite of a thin flexible brass wire through a hole at the end of the first row, takes up a number of bristles sufficient to half fill the hole, if inserted in lengths, and passes through the wire loop a portion of the root ends of this tuft, previously made to lie square and even by adjusting them between the finger and thumb, and trimming the tuft by pulling out stray bristles. She then pulls the wire firmly, the effect of which is to double up the tuft, and to pull the part thus doubled into the hole as far as it will go, until it is stopped by the resistance of the wood, or by the shoulder formed by the termination of the larger bore and the commencement of the smaller one. Then, bending the wire again into a loop, it is passed through the next hole, and another tuft of bristles being inserted, the loop is drawn as before. In this way the drawing proceeds, until a complete row is formed, when a man takes the t[illegible] and cuts off the ends of the roots of the bristles, to which the glue is attached, for [illegible] the proper length of the tufts which are to be left. If the brush is to be what is called a

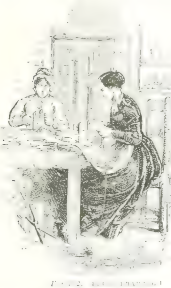
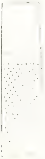


Fig. 372. Brush-drawing.(1)

penetrating brush, the bristles are cut of uneven lengths: otherwise they are reduced to the same level. If the bristles have been properly drawn, little or nothing is taken off the root ends; but the pieces cut off from the flag ends are often sufficient to form fresh series of tufts for inferior brushes, or they are worked up in a row of tufts just within the edge of the brush, where, having the heart or centre of the brush on one side, and the outermost row of tufts on the other side, to protect them, they are less exposed to wear. If the bristles are not very long, the drawing is continued without interruption until the stock is full, the [illegible] by hand. The following figures represent brushes in



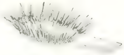


Fig. 374.

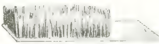


Fig. 375.

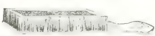


Fig. 373. Fig. 376.

their unfinished states. Fig. 373 is the back of a brush, drilled and drawn. Fig. 374 is the face of an [illegible] over it with the drawings. Fig. 375 the face of a brush with the heart tufted in with black bristles, surrounded by a border of white bristles. Fig. 376 is the same after it has been cut and finished. A skilful drawer will draw 800 tufts an hour; but many drawers do not average more than 400. A brush may be drilled with a number of holes varying from 100 to 800.

The drawing-wires at the back of the stock, Fig. 373, are covered over with a veneer, not only for the sake of appearance, but also to prevent the wires from injuring the hand in using the brush. In scrubbing and other brushes exposed to wet, the wire soon becomes corroded, notwithstanding the veneer; but, if the drawing be well done, the tufts are held so tightly that they will not give way, unless the brush be allowed to become very dry; in which case the contraction loosens the tufts, and they fall out with the wear. The [illegible] used by the beaver-hat maker resembles a common scrubbing-brush; but the bristles are drawn with cord instead of wire, which would be corroded by the hot acid liquor of the hat battery.

The veneer is applied to the back of the brush by holding both before the fire, then covering them with a layer of glue, and applying the glued surfaces together. They are screwed between the jaws of a number of hold-fasts, one of which is shown in Fig. 377, and these being screwed up tightly, the veneer in drying becomes firmly attached to the back of the brush. In some cases, a number of thin veneers (from two to six) of different coloured woods, are glued to the back, and in shaping the brush, these are cut obliquely, so that their chamfered edges present a number of lines of different colours.

During all these operations, the form of the brush is similar to one of the three Figs. 374, 375, or 376.

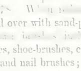


Fig. 377.

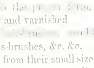


Fig. 378.

Fig. 379.

It is now to be reduced to shape, which is done by means of the spoke-shave, Fig. 379, and the scraper, Fig. 378. When reduced to the proper form, it is rubbed over with sand-paper and varnished.

Domestic brushes include hair-brushes, scrubbing-brushes, shoe-brushes, clothes-brushes, &c. &c. Also tooth and nail brushes; but, from their small size, and greater neatness of work, these latter form a distinct branch of the trade. In these, the bristles are drawn with a very thin wire [illegible] of silver, [illegible], in narrow grooves in the back, which are afterwards filled up with a hard red cement. The best sort of brushes are *trepanned*; that is, the drawing-holes, instead of being pierced completely through the back, are formed in the following manner. A number of tunnels are drilled through the thickness of the bone, either at the side or at the end; then a number of holes, corresponding with the number of tufts of bristles, are drilled in the face of the bone down into these tunnels; the tufts are then drawn with strong thread or silk, instead of wire, and lastly, the small lateral holes are plugged up with small pieces of bone or ivory, and the whole is smoothed and polished.

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(1) In this figure, the [illegible] drawn [illegible]. The stock round which the wire is wound [illegible] her right hand. Mr. Watters, who [illegible] "Although I never [illegible] be done in that way."

Brushes for cleaning bottles are formed by inserting a number of tufts of bristles between two or three parallel wires, at right angles to their length. Then, by twisting the wires together, the tufts are made to radiate around the central axis. Soft brushes, such as hat-brushes, are formed of horse-hair or goats'-hair. Some kinds of hard brushes are formed of strips of whalebone. The whalebone is boiled or steeped in water until it has become soft and flexible, so as to admit of being cut with a sharp instrument into thin shavings, which are split by a number of lances fixed in a handle. They are first cut into lengths of 9, 12, or 18 inches: the strips are then dried, and are used in the same manner as natural bristles. Coarse brooms, for stable and out-door use, are commonly made of *bass*, a hard, tough, dark-coloured vegetable fibre: birch and heath are also used. *Wisk* is a light-coloured vegetable fibre, used chiefly for carpet-brooms: and the finest variety is used in making brushes for cleaning velvet.

In 1830, Mr. Mason took out a patent for fixing the knots or tufts of brushes in dovetailed grooves formed in the stock, in order to supersede the slow process of drawing. Mr. Hancock has also a patent for the manufacture of brushes with flexible backs, in which the tufts are attached to yielding backs of leather.[1]

The Rev. Gilbert White, in his "Natural History of Selborne," mentions "a pretty implement of housewifery," which he had not seen anywhere else: "That is, little neat besoms, which our foresters make from the stalks of the *polytricum commune*, or great golden maiden-hair, which they call silk-wood, and find plenty in the bogs. When this moss is well combed and dressed, and divested of its outer skin, it becomes of a beautiful bright chestnut colour; and being soft and pliant, is very proper for the dusting of beds, curtains, carpets, hangings, &c. If these besoms were known to the brushmakers in town, it is probable they might come much in use for the purpose above mentioned." See APPENDIX.

BUDE LIGHT, see GAS.

BUHL-WORK, or *bool-work*, a term probably corrupted from *Boule*, and applied to any two materials of constrasted colours, inlaid with the saw. In France, the general term, *marqueterie*, is applied to such works, and to all kinds of inlaid work; and it is distinguished into *marqueterie en bois* and *marqueterie en metal*. It consists in representing flowers, animals, landscapes, and other objects, in their proper tints, by inlaying, without the aid of the artist's pencil: it also includes those geometrical patterns composed of angular pieces laid down in succession, after the manner of ordinary veneering, and to which the specimens of *parquetage* or inlaid floors belong. But the terms, *Buhl-work* and *Reisner-work*, appear to have originated in the names of the original inventors, two celebrated *ébénistes*, named Boule and Reisner—the one an Italian, and the other a German. The former settled in France in the reign of Louis XIV., and the latter in the time of Louis XIV. to XV. Their cabinet works were as much celebrated for their graceful forms as for their embellishment with inlaying. Boule chiefly employed dark-coloured tortoise-shell, inlaid with brass in flowing patterns, sometimes ornamented by the use of the graver. Reisner used principally as the ground tulip-wood, (*bois de rose*,) inlaid with flowers in dark woods. He also occasionally combined therewith bands and margins, in which the woods were contrasted as to the direction of the grain, as well as colour.

In buhl-work, as now constructed, the patterns generally consist of continuous lines, as in the honeysuckle ornament. To form this, two pieces of veneer, of equal size, such as ebony and holly, are scraped evenly on both sides, and glued together, with a piece of paper between. A piece of paper is also glued outside one of the veneers, and on this the design is sketched: a small hole is then made for the introduction of the saw, in a place where the hole will not be noticed in the pattern.

The saws used in piercing and inlaying differ but in size. The thin black line, Fig. 381, is the piercing-saw, attached to its handle and frame, *m*, and the dotted line, *w*, is the wooden frame of an ordinary buhl-saw: the former measures 8 inches from the blade to the frame; the latter 12 or 20 inches, to avoid the angles of large works. The wooden frames are made of three pieces of wood, halved and glued together, to form the three sides of a rectangle; after which, two pieces are glued upon each side, at an angle of 45°, across the corners: the whole, when

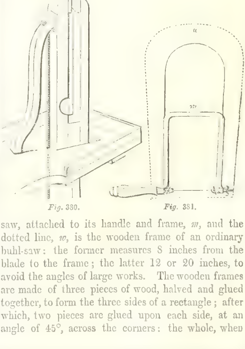

Fig. 380. *Fig.* 381.

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(1) For the illustrations and much of the information contained in this article, the Editor is indebted to Messrs. [illegible], Brush manufacturers, Tottenham-court Road, London.

thoroughly dry, is cut round to the form represented in Fig. 381.

The buhl-cutter sits astride a long narrow stool, Fig. 384, at one extremity of which are two vertical jaws, lined with leather at the top: one jaw is fixed; the other is jointed below, and springs open when left to itself, but is closed by a strut which is loosely attached to the stool by a tenon and mortise, and rests in a groove in the movable jaw. When the strut is pulled downwards by a string leading to the treadle, it closes the flexible jaw of the vice. The jaws are inclined some 20°, so as to be at right angles to the path of the workman's right hand.

Matters being thus arranged, the buhl-cutter inserts the saw into the hole in the veneers, and then fixes the saw in its frame. The work, held in the left hand, is placed in the vice, which is under the control of his foot, and the saw is grasped in the right hand with the forefinger extended, to support and guide the frame. "The several lines of the work are now followed by short quick strokes of the saw, the blade of which is always horizontal; but the frame and work are rapidly twisted about at all angles, to place the saw in the direction of the several lines. Considerable art is required in designing and sawing these ornaments, so that the saw may continue to travel uninterruptedly through the pattern, whilst the position of the work is as constantly shifted about in the vice, with that which appears to be a strange and perplexing restlessness. When the sawing is completed, the several parts are laid flat on a table, and any removed pieces are replaced. The entire work is then pressed down with the hand; the holly is stripped off in one layer with a painter's palette knife, which splits the paper, and the layer of holly is laid on the table with the paper downwards, or without being inverted. The honeysuckle is now pushed out of the ebony with the end of the scriber, and any minute pieces are picked out with the moistened finger; these are all laid aside. The cavity thus produced in the ebony is now entirely filled up with the honeysuckle of holly, and a piece of paper, smeared with thick glue, is rubbed on the two, to retain them in contact. They are immediately turned over, and the toothings or fine dust of the ebony are rubbed in, to fill up the interstices: a little thick glue is then applied, and rubbed in first with the finger, and then with the pane of the hammer, after which the work is laid aside to dry."[1] When dry, it is scraped at the bottom, and is then ready to be glued to the box or furniture to which it is to be applied: when the work is again dry, it is scraped and polished. The same course is pursued in combining the holly ground and the ebony honeysuckle, and these form the *counter* or *counterpart buhl*, in which the pattern is the same, but the colours are reversed.

Three thicknesses of wood, such as rosewood, mahogany, and satin-wood, may be glued together and cut as before. The three thicknesses, when split asunder and recombined, would produce three pieces of buhl-work, the grounds of which would be of rosewood, mahogany, and satin-wood, with the honeysuckle and counter of the two other woods respectively. Such are called "works in three woods," and form the cheaper kind of cabinet-boxes.

Brass buhl-works, or *Boule* work, are worked in narrow slips. The two parts, or the wood ground with brass scrolls, is laid down on the surface of one box or panel, and the counter, or the brass ground with wood scrolls, upon another.

When the material is small and costly, as pearl-shell, several pieces must be used: these are placed correctly edge to edge, so as to cover the entire surface to be ornamented. The pearl-shell, a portion of which is shown in Fig. 382, required eight pieces

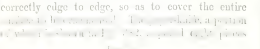

Fig. 382.

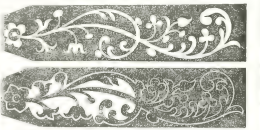

Fig. 383.

of pearl-shell. The counter, when glued on another veneer, is not inlaid of the irregular angular form of the rough pieces of pearl, but is cut round the general margin of the pattern, as in that portion of Fig. 383 which represents the counter to Fig. 382.

A more elaborate effect is produced by making the saw follow all the device of the counter, so as to leave a narrow line of pearl both within and without: this is called internal cutting, and is shown to the right of Fig. 383.

In the more minute buhl-works, the parts are not cut exactly square, but slightly bevelled, so that the pearl may be left a little larger than the interstices of the wood, to compensate for the saw kerf, and to make the fitting close, as regards the true buhl. The *stringings*, or the straight and circular lines combined with pearl buhl-work, are mostly of white metal, such as tin or pewter. Buhl-works of brass and wood are also sometimes made by stamping, instead of sawing. [See APPENDIX.]

BUILDING. An art which includes the practice of civil architecture, or the mechanical operations necessary to carry the designs of the architect into effect. "The execution of works of architecture necessarily includes building; but building is frequently employed when the result is not architecture: a man may be a competent builder without being an architect; but no one can profess himself a complete architect unless he be competent to specify and direct all the operations of building. A scientific knowledge of the principles of masonry, carpentry, joinery, &c., and of the qualities, strength and resistance of materials, though of the utmost importance to an architect, is not sufficient of itself, without

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(1) Holtzapffel, "Turning and Mechanical Manipulation," vol. ii.

a minute acquaintance with a great variety of less ambitious details. Such are those which relate to the arrangement of a plan for the greatest possible degree of convenience on the smallest space and at the least expense; its transference to the ground, the preparation and formation of foundations; the arrangement and construction of drains, sewers and cesspools; the varieties of walling with stone and of bonding bricks in brick-work; the uses of the various modes of bonding and tying walls with timber and otherwise; the arrangement of gutters on roofs, to get sufficient fall and to lead the water to the least inconvenient places for placing trunks to carry it down; the arrangement and formation of flues; the protection of walls from damps, of timbers from moisture and stagnant air, and of metals generally from exciting causes; the cost of materials and labour, and the quantity of each required to produce certain effects. Together with these it is important to be practically acquainted with all the modes of operation in all the trades or arts required in building. Everything must be clearly understood, or it will be impossible properly to specify beforehand, in detail, every thing and every operation to be done and performed; and minutely to estimate beforehand also the absolute cost involved in the execution of a proposed structure. The power to do the latter necessarily involves that of measuring work and ascertaining quantities after it is done. These things may certainly be referred to the surveyor or measurer, but they are not the less incumbent on the architect, who cannot be said to be thoroughly master of building, or the practice of his profession, unless he be skilled in these operations.

The foregoing enumeration of the duties of the architect, (from an excellent article on building by Professor Hosking, in the Encyclopædia Britannica), includes nearly all the processes concerned in building, and forms the subjects of separate articles in this work. See BRIDGE—SEWER and DRAINAGE—BRICKLAYING—STONE—MASONRY—MORTARS and CEMENTS—PLASTERING—CARPENTRY—WOODS—SLATING—PISÉ WORK—PLUMBING—GLAZING—PAINTING—WARMING and VENTILATION, &c. &c.

One of the most elaborate treatises on Building is by Rondelet. "Traité de l'art de bâtir," 5 vols. Quarto, Paris 1830—2, with a volume of illustrative plates in Folio.

BUOY. This term is supposed by Dr. Hickes to be derived from the French *bois*, wood, seeing that it is applied to the wood or block floating above an anchor, and fastened to it by a cable. In naval language the term buoy signifies any floating body employed to point out the situation of anything under water, as a ship's anchor, a shoal, sand-bank, &c. Buoys are of several kinds; the *Can-buoy* is in the form of a cone, Fig. 384, and is used to point out dangerous sands and shoals. When there are several of these near the same spot, as is frequently the case at the entrance of rivers, they are distinguished by different colours, being painted black, white, or red, or in various stripes and patterns. Red is the best colour, for in some states of the sea both black and white buoys become indistinct. The can-buoy has its apex downwards, and is painted on the least exposed surface. The *Cask* or *Cable-buoy* may be either a common cask used for the purpose, or it may be made in the form of a cask, or double frustum of a cone: it is also frequently in the form of a cylinder. The larger buoys of this kind are used for mooring, the smaller for cables, hence they are called *Mooring-buoys* and *Cable-buoys*. *Nun buoys* are casks which are large in the middle, and taper greatly towards the two ends, Fig. 385. *Life* or *Safety-buoys* are intended to save a person

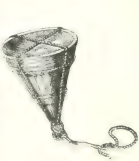


Fig. 384.

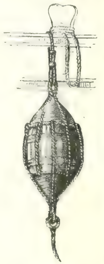


Fig. 385.

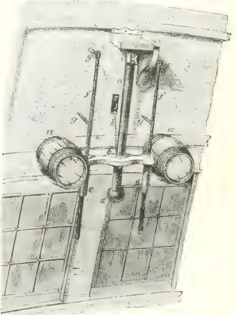


Fig. 386.

who fall overboard, and they have been even constructed with a view to supporting several persons in case of shipwreck. The most esteemed single Life-buoy is that of Lieut. Cook of Plymouth, which is generally called a *night life-buoy*, because when an accident happens at night, it can be immediately lighted before it is let go, being provided with port-fire and lock for that purpose. Fig. 386 gives a perspective view of this life-buoy suspended over the two middle windows of a frigate stern; *aa* are two casks connected by the bar *b* passing through them, *c* a staff, *d* a ballast weight at the bottom to keep it upright; *ee* two wooden pipes firmly fixed to the bar *b*; these pipes slide on two metal rods *ff*, which are fastened to the stern at *gggg*; a chain *h* suspends the life-buoy and with the rods keep it tight to the stern; a copper cap is hinged to the stern at *k*, this covers the copper table which carries the port-fire, and defends it from the weather. This port-fire is lighted by means of a barrel *p* at Fig. 387, which pulls the trigger; a bolt is then drawn, which lets go the chain by which the life-buoy is suspended to the stern. This bolt *r* is shown at Fig. 388, in the position it is in when, being withdrawn, it has unlocked the roller *q*, which has therefore turned round and let go the chain it previously supported. The buoy with its lighted port-fire then falls into the water and forms a common point of resort both to the person in the water and the boat sent out to save him. The inventor obtained the gold medal of the Society of Arts, and his buoy is now in common use. A variety of other buoys and life-preservers have been brought forward from time to time. Thus, Lieut. Irvine has contrived a safety portmanteau capable of excluding moisture and of buoying up a person in the water. Capt. Hervey's life-preserver is a light wooden frame shaped like a horseshoe, but sufficiently wide to admit a man's body, and rendered buoyant by means of cork. Mr. Taylor of Leith has devised a deck seat 28 inches long by 18 broad, capable of being quickly converted into a tight boat-shaped vessel nearly 4 feet long, in which one person can float. Safety jackets and belts are numerous, and Messrs. Mackintosh have introduced a life-cloak or cape consisting of a double thickness of cloth; the space between being inflated with air forms a boat capable of floating the person. Mr. Reeve has invented an India-rubber pad or cushion to be attached to the back to enable the wearer to float in water: a wire gauze mask is tied over the mouth and nostrils which admits air but repels water. Mr. Symington's jacket or belt admits of being quickly put on, and has sufficient buoyancy to keep the head of the wearer above water. It unfortunately happens with contrivances of this kind, that when there is no danger they are neglected and forgotten, so that when most wanted they are either not to be found or they are out of repair, or unmanageable. [See Buoy.]

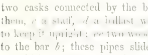


Fig. 387.

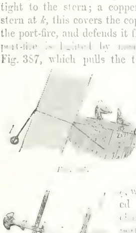


Fig. 388.

BURNER. See Gas—Lamp.

BUTTER. An oily compound forming one of the components of milk, the others being curd or *caseine*, a species of sugar, and certain salts. The lighter matters suspended in milk separate in the form of cream, and this cream, by churning, becomes separated into *butter* and *butter-milk*. "During this process the temperature of the cream is slightly raised, a little oxygen absorbed, and acid produced; but this change is not essential to the separation of the butter, which takes place when air is excluded, and depends upon the rupture of the oil globules." *Brande.*

A description of the process of butter-making belongs properly to a work on rural economy, but for the sake of the simple machinery connected with it, we give a brief sketch of it. When the milk is brought into the dairy, it is strained through a fine sieve, and poured into shallow pans to the depth of four or five inches, where being exposed to a draught of cool air from opposite windows cream rapidly forms on the surface. This cream, skimmed off and churned immediately, produces the most delicate kind of butter, but it is seldom used at once, but left twenty-four hours, and then skimmed and consigned to a deep earthen jar whose contents are churned every two days. Churning is merely the beating and agitating of the cream in a wooden vessel, the simplest form of which is that of an upright wooden cask, Fig. 389, having a round lid with a hole in the centre. Through this hole a stick passes, which is four or five feet long, and has at the lower end a round flat board with holes in it. This board is a little smaller than the top of the cask, and is worked briskly up and down within it, keeping the cream violently agitated. The same purpose of keeping the cream constantly agitated is answered by the *barrel-churn*, Fig. 390, which turns on an axle by means of a common winch, and is sometimes moved by horse-power, or even by steam. The cream is strained into the churn through a cheese-cloth, which is first dipped in water and spread over the top of the churn, if it be an upright, or over the bung-hole if it be a barrel-churn. A cheese-cloth is also kept round the openings of the churn during the operation, or some of the cream will be dashed out in churning. Experience teaches

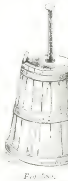
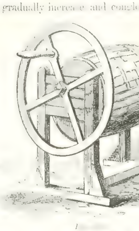


Fig. 389.

the best speed for churning, for if too quick or too slow, the butter becomes soft and frothy or strong and ill-flavoured. The butter appears first in kernels which gradually increase and conglomerate together in masses: when all the butter is "come," the remaining butter-milk is set aside for the pigs, and the butter itself is repeatedly washed with spring-water in a shallow tub, and worked with the hand or with a wooden beater, or with a cheese-cloth rolled up in a ball. This working and washing is for the purpose of freeing the mass from all the remaining butter-milk. When this is perfectly accomplished, the butter is weighed out into pounds or half-pounds, and printed or rolled as may be the fashion of the district. The print is of wood, with a small air hole in the centre. The butter is pressed down upon this pattern, shaped round the edges, and then flattened a little upon a marble or wooden slab. The print is then loosened from it by a smart blow. A large portion of butter from most considerable dairies, is however, immediately salted, and put into casks or firkins of clean white wood containing about fifty-six pounds weight. Peculiar customs in certain districts lead to varieties in the quality of butter: for instance, Devonshire butter and cream owe their celebrity not so much to the superior richness of the pastures, as to the dairy practice of that county, which differs in the following particulars. The milk, instead of being left to cream slowly in a cool place, is placed in large and deep pans, and warmed on an iron plate over a small furnace. A thick scum rises on the milk, and a little of this is removed from time to time with a spoon, to watch for the first appearance of bubbles on the surface. When these appear and before boiling begins, the milk is taken off and allowed to cool. The thick part is then removed, and is the famous clouted cream, a substance nearly as thick as butter. The butter of Epping and Cambridge is very highly esteemed in the metropolis, and that of several other counties is passed off as such. The salt butter of Holland is superior to that of any other country, and forms about three-fourths of all the foreign butter we import.



Butter is naturally of a yellow colour, and is deepened when the cows are fed in rich pastures, but an artificial colouring is also largely employed, being either the juice of carrots, or arnotto, generally the latter. [See Arnotto.] An experienced writer gives the following estimate of the quantity of butter produced by a single cow. "A good cow should produce six pounds of butter per week in summer, and half that quantity in winter, allowing from six weeks to two months for her being dry before calving—that is, 120 lbs. in twenty weeks after calving, and 80 lbs. in the remainder of the time till she goes dry,—in all about 200 lbs. in the year. If she produces more, she may be considered a superior cow, if less, she is below par. To produce this quantity the pasture must be good; and if we allow three acres to keep a cow in grass and hay for the year, which is not very far from the mark, the butter made will produce about 10*l.* at the distance of fifty miles from London, if it is sold in a fresh state, and the calf about 15*s.* at a week old. This does little more than pay rent and expenses: the profit must be made by feeding pigs, or making skim milk cheese."

The production and consumption of butter in Great Britain is immense. The consumption in the metropolis has been averaged at 10 lbs. a-year per head, and this, with a population of 2,500,000, would give 25,000,000 lbs., or 11,160 tons. When to this is added 5,000 tons allowed to be required for the victualling of ships, &c., the total consumption, in round numbers, rises to 16,000 tons, or 35,840,000 lbs., which, at 10*d.* per pound, would be worth 1,193,333*l.*

BUTTON. An article of utility, the manufacture of which includes many curious and interesting processes. These vary greatly, according to the multiform materials used in button-making, namely, metal, horn, shell, glass, wire, mother-of-pearl, jet, precious stones, linen, velvet, satin, florentine, and embroidered stuffs of all kinds.

Birmingham is the great seat of this manufacture, which once held the foremost rank among the "toy-trades" of that busy town, and still forms an important feature in its proceedings. Hutton, in noticing the caprices of fashion with respect to this article, says: "This beautiful ornament appears with infinite variation; and though the original date is rather uncertain, yet we well remember the long coats of our grandfathers, covered with half-a-gross of high-tops, and the cloaks of our grandmothers, ornamented with a horn button nearly the size of a crown-piece, a watch, or a john-apple, curiously wrought, as having passed through the Birmingham press. Though the common round button keeps on with the steady pace of the day, yet we sometimes see the oval, the square, and the pea, the concave and the pyramid, start into existence. In some branches of traffic the wearer calls loudly for new fashions; but in this, the fashions tread upon each other, and crowd upon the wearer. The consumption of this article is astonishing; and the value in 1781 was from threepence to 140 guineas a gross. In 1818, the art of gilding buttons had arrived at such a degree of refinement, in Birmingham, that three-pennyworth of gold was made to cover a gross of buttons."

The gilt button manufacture, which thus excited Hutton's astonishment, will be the first we shall notice. Sheet-copper, with a small alloy of zinc, is the material employed. This is furnished to the button-maker in strips of the exact thickness to suit his purpose. A corner of one of these strips is placed upon a circular die or bed in a fly-press, and when the handle of the press is pulled forward, a circular cutter or punch descends, and punches out a round disc of the copper, technically called a *blank*. This being removed, the strip of copper is shifted, and another blank cut out; and so, with great rapidity, and by female hands, this process is repeated, at the rate of about thirty blanks per minute, or twelve gross in an hour. Numerous and various fly-presses are at work at the same time, with one female to each; therefore, the total number of blanks produced in an hour is very large. This first process for gilt buttons is also common to the other varieties.

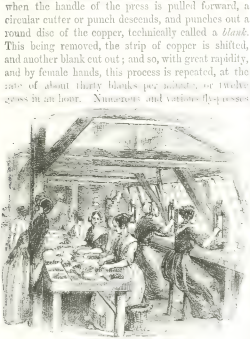


Fig. 391. PUNCHING BLANKS.

But besides the common gilt button, which is flat on both sides, there is the convex button, such as is worn by pages. To produce this, the blanks are placed one by one in a fly-press, having a concave mould and a convex punch, which, being brought down upon the soft metal, forces it into the bed, and gives it the required shape. This is also the business of women, and is performed with skill and celerity. But there are other buttons in which the convex front is closed in behind with another piece of metal, also convex on the outer surface, but less so than the front. These are called *shell* buttons. The two pieces or blanks are made separately, and brought together afterwards by the action of a die and punch, whereby the edge of the shell is bent over and lapped neatly down upon the bottom without any soldering. Metal brace-buttons, and others which have holes through them instead of a shank, are made first by stamping out the blanks, then making them a little concave in the middle with a punch at a fly-press, next piercing the holes with a punch, and then rubbing down their edges with a blunt steel tool to prevent them from cutting the thread. To return to the simple blank: when it is cut, the edges are exceedingly sharp, and require to be smoothed and rounded. For this purpose, they are rolled between two parallel grooved pieces of steel, Fig. 392, about eighteen inches long, one movable, the other fixed. In each grooved piece is a semicircular opening, which, by corresponding once during each revolution of the handle, allows a blank to be dropped into the grooves, and this blank, revolving as it proceeds between the two pieces of steel, reaches a hole at *a*, and drops through into a basket beneath. This operation is carried on rapidly by a boy, who places the blanks in the cavity with one hand, while he turns the handle with the other. The blanks are now ready to be planished on the face, and this is done by placing them one by one in a die under a small stamp, and allowing them to receive a smart blow from the falling of a polished steel hammer. In this state they are ready to receive the *shanks*, or little metal loops, by which they are attached to the dress.

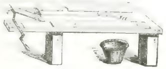


Fig. 392.

The manufacture of button shanks is a distinct branch of trade at Birmingham. They are made of brass wire, and vary in weight from eight to forty gross in the pound. A coil of wire is placed in a machine, which gradually advances one end of the wire to a pair of shears, where short pieces are successively cut off. A metal finger then presses against the middle of each short piece, bending it, and at the same time forcing it between the jaws of a vice, which compresses it, so as to form an eye: a small hammer then strikes the two ends, spreading them out into a flat surface, when the shank is pushed out of the machine as ready for use. Millions of shanks are made in this way in the course of a year. The office of attaching them to the blanks is assigned to women, who, while seated at a bench, adjust them in their proper position by means of a small spring clasp of iron wire, shaped like sugar-tongs, one limb of which rests on the top of the shank, the other on the face of the button. A little solder and resin are at the same time applied to the spot where the two are in contact, and this, when the buttons are afterwards placed by hundreds on iron plates in an oven, melts, and combines the two, causing them, on cooling, to be firmly united together. The button is now complete as to outward form, unless it have to be decorated with a crest or inscription; in which case a die containing the device reversed is attached with its face downwards to a heavy weight or monkey, moving between two upright posts, and suspended by a cord passing over a pulley, and ending in a stirrup-iron, into which the workman inserts his foot. On the solid bench beneath this monkey another die is firmly fixed, containing the maker's name reversed, and a hole for the shank. When the shank is inserted in this hole, the face of the button is exposed upwards, and is ready to receive the impression from above. This is given by the workman withdrawing his foot from the stirrup, which lets the

[illegible]

weighted end fall with great force, and thus stamps the device in relief on the face of the button, while at the same time the maker's name is stamped on the back. The workman then presses on the stirrup, thus raising the weight, and quickly removes the stamped button, and with the other hand puts a plain one in its place

The succeeding processes are ornamental, for at this stage the buttons, though perfect in shape, are exceedingly dull and unattractive. They are first cleansed, by being stirred up in a weak solution of nitric acid; then boiled, and after boiling while in a perforated earthen dish, dipped into a stronger acid solution; then washed and dried. They are now ready either to be silvered or gilded, as the case may be. For the former, they are put into an earthen vessel, containing a mixture of silver, common salt, cream of tartar, and some other ingredients, and well stirred for a minute or two. This gives them a silvery white surface. For the latter, much greater care is required, in order to economise the gold. In some cases, the gilding is only to be applied to the face of the button, which is then called a *top;* in others, to the whole surface, making what is called an *all-over.* For the latter purpose, the buttons are first pickled in dilute sulphuric acid, and then immersed in a solution of nitrate of mercury, called *gold water*, which leaves a thin film of mercury over their whole surface. If tops are to be made, the buttons are not immersed, but arranged on a board (in which there are holes for the shanks), and brushed over their faces with the liquid. Owing to the astonishing divisibility of gold, five grains are sufficient to gild 144 one-inch buttons, and sometimes two-and-a-half grains are made to serve the purpose. A few grains of gold-leaf dissolved in about ten times its weight of mercury is the amalgam used in gilding. It is gently heated in an iron ladle, and stirred with an iron rod, then poured into cold water, and finely strained through wash-leather, to remove the superfluous mercury. The mass left in the leather is in a semi-fluid state: this is dissolved in dilute nitric acid, and the buttons stirred about in the solution, for all-overs, or merely brushed on the face, for tops. The buttons do not at this period present the slightest appearance of gold: they are of a dull silvery colour, due to the excess of mercury which has dissolved the gold. The next process, therefore, is to drive off all the mercury by heat, and so allow the gold to become visible. This was formerly done at great loss, both of the material and of the health of the work-people, over an open fire, but is now managed by placing the buttons in a wire cage, within a furnace, constructed to preserve and condense the fumes of the mercury, by allowing of their escape into a vessel containing water, instead of being diffused through the room and poisoning the work-people. Under the present arrangement, a woman can sit without danger and turn the handle of the cage, thus exposing all the buttons in succession to the action of the fire. From this process, which is called *drying-off*, the buttons certainly come forth of a gold colour, but it is still of a dull and unpleasing hue. To give the requisite polish which

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is characteristic of a new gilt button, they are now removed to the lathe, and carefully burnished with bloodstone, which completes the process.

The gilt-button manufacture has suffered greatly on account of the prevalence of other fashions in this article. The florentine and the silk button have nearly superseded it, and these have been carefully improved from time to time, and made the subject of various patents. In one of these, the fabric for covering the buttons is expressly woven for the purpose, and contains portions of ornamental designs placed at suitable distances for cutting up into circular pieces for covering buttons. The material may be of satin, sarsnet, twill, &c., with an ornamental central figure of any kind. The ground of the florentine button are numerous, and the manufacture is very ingenious. All the different parts are cut out at a fly-press: they are, first, a metal shell, of which a front and side view are shown in Fig. 595, No. 1; secondly, a metal collet, with an oblong hole for the shank of the button (No. 2); thirdly, a circular piece of silk or other woven material (No. 3); fourthly, the padding, which lies under the collet, and which has a thread wound round it, at right angles to the oblong hole of the collet (No. 4). This padding is made up of several layers of soft paper, and a layer of silk over them, the whole forming the back of the button. After all the pieces are cut out, the circular piece of silk (3) is first placed on the face of the die or mould (shown in section at No. 5); the metal shell (1) is then placed on the silk covering, and the two together are pressed down to the bottom of the die by means of a punch, which nearly fits the hollow of the die. This punch is then removed, and a hollow tool (6) forced into the die, by which the edges of the silk are forced toward the centre, thus overlapping the shell. The collet (2) with the padding (4) is then dropped into the mould through a hollow tool (7), the collet being uppermost. A punch is then passed down within the hollow tool, forcing the padding and the edges of the outer covering of the button into the shell, which retains them with sufficient firmness until the button undergoes its final pressure. The button, thus far advanced, is removed from the die by a wire passed up through a channel made for the purpose. The final pressure is given by a punch with a plain face, the workman holding a piece of tissue-paper between the punch and the face of the button, to prevent injury to the latter. In this kind of button there is no projecting shank, but a flexible one through which the needle can be easily passed. By a recent improvement, this final pressure is given by the punch and die which are employed for covering the front shell and bringing the parts of the button together. This is not an unimportant circumstance, though it may seem a trivial one; for, by lessening the number of processes which an article of manufacture has to go through, the cost is lessened also, and the patentee has the preference in the market, and a decided advantage over his fellow manufacturers.

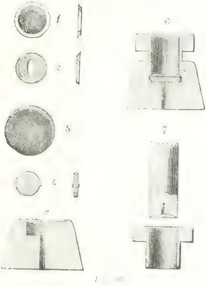

Fig. 595.

CABLE, see CHAIN-CABLE—ROPE.

CACAO, see COCOA.

CADMIUM (from καδμεια, a term formerly applied to calamine and to the substance which sublimes from the furnace during the manufacture of brass. Cadmium is a simple metal, and was discovered in 1818 by Stromeyer, while he was seeking to ascertain the cause of the yellow colour of certain oxides of zinc. It has since been found in several varieties of zinc ore. It is a white metal, resembling tin, and, like it, creaks when a rod of it is bent. It is malleable and ductile, and soft enough to leave marks on paper. Its sp. gr. is 8·6 or 8·69 after hammering. It fuses at 442°, and boils at 1580°. Air scarcely acts upon it except when heated to redness, and then it forms an orange-coloured oxide. The equivalent of cadmium is 56, and its symbol Cd. This metal has not been used in the arts.

CAFFEINE, see COFFEE.

CAISSON, see BRIDGE.

CALAMANCO, a kind of woollen stuff chequered in the warp, so that the checks are seen on one side only. See WOOL.

CALAMINE, a native carbonate of zinc. See ZINC.

CALCAREOUS EARTH, a term commonly applied to lime in any combination.

CALCAREOUS SPAR, crystallized native carbonate of lime, of which the primitive form, as it occurs in *Iceland spar*, is an obtuse rhomboid of 105° 5′ and 74° 55′. Its specific gravity is 2·72. The secondary forms are more numerous than those of any other substance. Bournon in his *Traité de Minéralogie* has described and figured 600 modifications. [See LIME.]

CALCEDONY, see AGATE.

CALCINATION, a term now synonymous with *oxidizement* or *oxidation*. When metals are heated in oxygen or with access of atmospheric air, many of them lose their metallic character, and become *oxides* or *calces*, as they were formerly termed. See METALS.

CALCIUM, the metallic base of lime. See LIME.

CALCULATING MACHINES. Mathematical calculations, from the simple processes of arithmetic, to the refined operations of algebra and geometry, enter so largely into the common concerns of life, or by their results are of such inestimable value to trade, commerce, navigation and science, and consequently more or less directly to every member of a civilized community, that any successful attempt to reduce the slow and often erroneous operations of the mind to the rapid and precise performances of a machine, must be regarded as a public benefit. But as the human mind cannot spring at once from a state of ignorance into one of knowledge; as an imperfect condition of science cannot suddenly approach perfection; as all our knowledge and all our discoveries must be made by slow and painful steps; as the human mind requires the strong illuminating power of present knowledge, to penetrate even a short distance into the unknown and unexplored region of discovery, so we may readily suppose that the invention of a machine so truly wonderful as that contrived by Mr. Babbage, must have been the offspring of an old family of machines, professing the same object, but accomplishing far less. That this is so, detracts nothing from the last inventor, for had there been no other calculating machines previous to his, he could have gained nothing from the experience of the past, and consequently his machine, instead of being almost perfect, might have been only a germ for future men of genius to improve upon. But not only machines, but mental processes which give birth to machines, pass through various phases of improvement in the course of ages. There was a time when our forefathers could perform the arithmetical operation of addition, but not that of multiplication. It was discovered, however, that without greatly changing the character of addition, its processes might be facilitated by arranging and committing to memory a sort of table in which the results of addition are presented for the combinations of units from 1 to 12. Thus when we multiply 9 by 6, we add up 9 six times; but in the table we lose sight of the process of addition, and simply take the result as it stands, 9 × 6 = 54. In like manner division was introduced as a speedier method of subtraction; for if we have to divide 30 by 5, we in effect subtract 5 from 30 six times over, by which we separate 30 into six parcels of 5 each.

One of the simplest forms of calculating machines, is the *Abacus*. The school-boys of ancient Greece acquired the elements of knowledge by working on a smooth board with a narrow rim, called the *Abax*, probably from the combination of Α, Β, Γ, the first letters of their alphabet. They were instructed to compute by forming progressive rows of counters, which consisted of small pebbles, of round bits of bone or ivory, or even of silver coins. The same board also served for teaching the rudiments of writing and the principles of geometry, for by strewing the abax with sand, it was easy with a small rod to trace letters, draw lines, construct triangles, or describe circles. It appears also, that the practice of bestowing on pebbles an artificial value, according to the rank or place which they occupied, was practised at a very early period, for Diogenes Laertius states that Solon used to compare the passive ministers of kings or tyrants, to the counters or pebbles of arithmeticians, which are sometimes most important, and at other times quite insignificant. The Romans borrowed their abacus from the Greeks, and to each pebble or counter used on the board, they gave the name of *calculus*, the diminutive of *calx*, a stone; and applied the verb *calculare* to the operations performed with such pebbles; whence the English verb to calculate. (The Greeks also derived their verb, ψηφίζειν, to compute, from ψῆφος, a pebble.) A small box or coffer, called a *loculus*, with compartments for holding the counters, was a necessary appendage of the abacus: so that, "instead of carrying a slate and satchel, as in modern times, the Roman boy was accustomed to trudge to school, loaded with his arithmetical board, and his box of counters."[1] The abacus appears to have been divided by means of perpendicular lines or bars: this was improved by dividing the surface of the board by sets of parallel grooves, or by stretched wires, or even by successive rows of holes. It was easy to move small counters in the grooves, to slide perforated beads along the wires, or to stick large nobs in the different holes. To diminish the number of marks required, each column was surmounted by a shorter one, wherein each counter had the same value as five of the ordinary kind, being half the index of the denary scale. Two of these instruments, delineated on the antique monuments, show clearly how they were used. In one the numbers are represented by flattish perforated beads, ranged on parallel wires; and in the other they are expressed by small round counters, moving in parallel grooves. These instruments contain each seven principal bars, expressing in order units, tens, hundreds, thousands, ten-thousands, hundred-thousands, and millions; and above them are shorter bars, following the same progression, but having five times the relative value. With four beads on each of the long wires, and one bead on every corresponding short wire, any number as far as ten millions could be expressed. Immediately below the place of units is a bar with its corresponding branch, both intended to signify ounces, or the twelfth parts of a pound. Fractions of ounces are also expressed by three very short bars behind the rest.

During the middle ages, calculations were performed on the principle of the abacus, by representing numbers by counters placed in parallel rows. It was the usual practice for merchants, auditors of accounts, or judges appointed to decide in matters of revenue, to appear on a covered bank or bench; before them was a table covered with a cloth, resembling the abacus, and distinguished by perpendicular and *chequered* lines. The Court of Exchequer, which takes cognisance of all questions of revenue, was introduced at the Norman Conquest. A writer of the twelfth century describes this table or *scaccarium* as being about ten feet long and five broad, with a ledge or border about four inches high, to prevent anything from rolling over, and was surrounded on all sides by seats for the judges, the tellers, and other officers. It was covered every year after Easter Term with fresh black cloth, divided by perpendicular white lines, at intervals of about a foot, and again parted by similar transverse lines. Small coins were used for counters: the lowest bar exhibited pence, the one above it shillings, the next pounds; and the higher bars denoted successively tens, twenties, hundreds, thousands, and ten-thousands of pounds. The first bar, therefore, advanced by dozens, the second and

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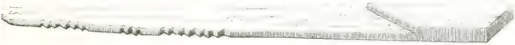
(1) Encyclopædia Britannica, Art. *Abacus*.

third by scores, and the rest by multiples of ten. The teller sat about the middle of the table: on his right hand eleven pennies were heaped on the first bar, and a pile of nineteen shillings on the second; while a quantity of pounds was collected opposite to him on the third bar. For the sake of expedition, he might employ a different mark to represent half the value of any bar; a silver penny for ten shillings, and a gold penny for ten pounds.

Offices for changing money were indicated by a chequered board, a sign afterwards adopted for an inn or hostelry.

The method of recording numbers by tallies was also introduced into England at the Norman Conquest. Tallies are well seasoned sticks of hazel or willow, Fig. 396, from the French *tailler*, to cut, because they are cut or squared at each end. The sum of money was marked on the side with notches by the cutter of tallies, and also inscribed on both sides in Roman characters by the writer of tallies. The smallest notch denoted a penny, a larger one a shilling, and one still larger a pound; other notches increasing in breadth denoted a ten, a hundred, and a thousand. The stick was then cleft through the middle by the deputy chamberlains with a knife and a mallet, the one portion being called the *stock*, and the other the *counter-tally*.



The Chinese make use of an ancient instrument called the *Swan-pan*, or *computing-table*, which is similar in shape and construction to the abacus of the Romans. It consists of a small oblong board surrounded by a high ledge, and parted lengthwise near the top by another ledge. It is divided vertically by 10 smooth and slender rods of bamboo, on which are strung 2 small balls of ivory or bone in the upper compartment, and five such balls in the lower and larger compartment: each of the latter on the several bars denoting a unit, and each of the former a 5. As the decimal notation is used in China, this instrument is well adapted for facilitating calculation, and the native traders are said to use it with such rapidity and skill as to astonish Europeans.

The Chinese also make use of digital signs for denoting numbers, (as did also the ancient Romans, whence the term *digit* from *digitus* a finger.) As every finger has 3 joints, let the thumb nail of the other hand touch those joints in succession, passing up the one side of the finger, down the middle and again up the other side, and it will give 9 different marks applicable to the denary scale of arrangement. On the little finger those marks signify units, on the next finger tens, on the middle finger hundreds, on the index finger thousands, and on the thumb tens of thousands. With the combined positions of the joints of one hand therefore it is easy to advance by signs as far as a million. The merchants of China are said to conclude bargains with each other by means of these signs, and that often with a fraudulent design they conceal them from the by-standers, by seeming only to seize each others' hands with a hearty grasp.

A simple form of arithmetical machine was invented by Baron Napier of Merchiston, the inventor of logarithms. It is called *Napier's bones* or *rods*. It consists of a number of rods or square parallelopipeds 3 inches in length and 2-10ths of an inch in breadth, Fig. 397. Each of the faces of the parallelopipeds except the *index-rod* on the left hand is divided into 10 equal squares, which are cut diagonally by a line from right to left downwards. In each square is inserted the product of two significant figures, so that the whole when placed together forms the common multiplication table; the only difference being that the right hand or unit figure of the product is placed below the diagonal line, and the 10 belonging to it above it; and when the product is but one figure, it is written below it. With these rods, multiplication and division can be performed by means of addition and subtraction; but as the same figure may occur several times, it is necessary to be provided with 3 or 4 rods of each kind, and to have 4 sides of each rod inscribed with a different set of figures. Multiplication is performed by placing the rods so as to form the multiplicand at the top; then apply a rod with unity at the top to the left hand side, and exactly opposite to each figure will be found the product arising from the multiplication of that figure into the multiplicand; but this must be obtained by addition, in the following manner:—the figure below the diagonal on the right-hand rod, is the unit figure of the product; the figure above the diagonal, added to the figure on the next rod below the diagonal, gives the next figure of the product; the figure above the diagonal on the second rod, added to the figure below the diagonal on the following rod, gives the third figure of the product; and so on. It will not be necessary to illustrate the use of these rods by examples, for the multiplication

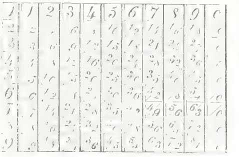


Fig. 397.

table is so well and so generally known, as to render the tedious use of Napier's rods unnecessary. The method of performing division therewith, is even more complex than that of multiplication.

Many other contrivances for facilitating calculation have been made from time to time, but they take the place of *instruments* rather than of *machines.* The first calculating machines properly so called are those by Gersten and Pascal, the former of which is described by Professor Gersten himself, in an early number of the *Philosophical Transactions,* and the latter is described by Diderot in the *Encyclopédie Méthodique,* article *Arithmétique.*

It would not be possible to describe these machines without the aid of elaborate engravings. Their use, if indeed they were ever used practically, was confined to a few simple arithmetical operations, which can be performed much more readily by the pen of a skilful computer. It will, however, be useful to notice the principle upon which these machines were constructed, since it is that which has been subsequently adopted in later and more efficient machines of this class. If we notice the manner in which quantities are combined in the common system of numeration, it will be found that the value of each figure is ten times greater than it would be if it occupied a position one place to the right. Thus, in the number 1829, although 9 is greater than 2, yet the 2 in this position represents a larger sum than the 9, because it occupies a place to the left of the 9. The quantities really expressed by the figures 1829 are $\left\{\begin{array}{r}1000\\800\\20\\9\end{array}\right\}$, but in practice we omit the cyphers, and place the significant figures side by side preserving their proper position from the right hand. Now if we have a wheel on whose axis is a pinion with leaves or teeth; if these teeth work into another set of teeth or cogs on the periphery of another wheel, and if the teeth on the latter wheel are just ten times as numerous as those on the pinion, this system being made to revolve, the pinioned wheel will revolve just ten times as fast as the other. This produces a kind of analogy between the decimal notation and the working of the wheels; for it takes 10 units to make up 1 figure or unit in the second place in common numeration, and it requires 10 revolutions of the pinioned wheel to impart 1 revolution to the larger wheel. This is the fundamental principle in the calculating machines now under notice. In such machines there are a number of dial-faces, each marked with figures from 1 to 10. These dial-faces are fixed upon wheels, the teeth of which work into the pinions of other wheels, on which are similarly divided faces or discs, so that while one face indicates units, another indicates tens, a third, hundreds, and so on. These wheels and dial-faces may be differently arranged in different machines, but the principle is the same in all. In Gersten's instrument, for example, if 32 were to be added to 59, two dial-faces had to be turned by hand until two needles pointed to the two figures 5 and 9, one on each plate: two slides were then adjusted, until two indices pointed to the figures 3 and 2, one on each slide. Both the discs and both the slides were connected with toothed rack-work, which working into each other, turned another dial-plate in such a direction as to show on its face 91, or the sum of 32 and 59. If on the contrary it were required to subtract 59 from 91, indices would be pointed to 9 and 1 on two separate discs, and to 5 and 9 on two separates slides, and the movement of these discs and slides in an opposite direction to the former would turn another wheel, to show 32 on its face, the difference between 59 and 91. The process of multiplication was effected by a kind of reiteration of additions, and that of division by a succession of subtractions.

Pascal's machine was constructed for the purpose of performing certain calculations connected with the duties of an office, held in Upper Normandy by Pascal's father. The calculations were reckoned in the currency of France at the time: the *denier* wheel had 12 teeth, representing the number of deniers in a *sol;* the sol wheel had 20 teeth, equal to the number of sols in a livre, above which each wheel had 10 teeth, indicating 10, 100, 1000, &c. livres. Connected with the wheels were a number of cylinders. The cylinder expressing deniers had the following figures engraved upon it:—

0 11 10 9 8 7. 6 5 4 3 2 1.
11. 0 1 2 3 4. 5 6. 7 8 9 10

The cylinder representing the sols:—

0 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
19. 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

And when it expressed the units of the livres or pounds:—

0 9 8 7 6 5 4 3 2 1.
9. 0 1 2 3 4 5 6 7 8

Now as matters are so arranged in this machine that a complete turn of the first barrel is necessary to produce a twentieth of the second; a turn of the second to produce a tenth of the third; a turn of the third to produce a tenth of the fourth; and in short, since the barrels follow in their revolutions the proportion which prevails between the different orders of the figures in arithmetic, it is evident that the operations of numbers may be performed by means of the barrels and the figures which are engraved on them.

This machine has some ingenious arrangements which we cannot stay to describe: it is, however, tedious in its operations and inferior to the common modes of performing arithmetical calculations. It is introduced here in order to furnish a glimpse of one of the predecessors of Mr. Babbage's machine. It was improved by M. de l'Epine in 1725, and again in 1730 by M. Boitissendeau. Both machines are described in the "Recueil des Machines approuvées." About 1670, Sir Samuel Morland contrived two machines, one for addition and subtraction, and the other for multiplication, division, and the extraction of the square and cube roots. They are described in the Philosophical Transactions, No 91. Leibnitz s also said to have invented a calculating machine, but no account of it appears to have been published.

But machines of this kind, however ingenious, were not directed to the supply of a want which had long been really felt; namely, the production of arithmetical and other tables which should be rigorously correct. In the navigation of a ship, in the preparation of an almanac, in the higher branches of astronomy, and in other occupations, the use of such tables is very great. As such tables are constructed by human heads and hands, they are all more or less disfigured by errors. Tables of multiplication, of powers and roots, of trigonometrical elements, of logarithms, of the solar, lunar, and planetary motions, &c., have been computed and published in various countries, to the extent of many hundred volumes; and although very great care has been bestowed on their preparation, they all contain errors of greater or less magnitude. In a multiplication table (as far as 100 times 1,000) constructed by Dr. Hutton for the Board of Longitude, 40 errors were discovered in a single page taken at random. In the solar and lunar tables from whence the computations were formerly made for the Nautical Almanac, more than 500 errors were discovered by one person. In the "Tables requisite to be used with the Nautical Almanac," more than 1,000 errors were detected. In certain tables published by the Board of Longitude, a table of errata, containing 1,100 errors, was affixed. It was afterwards found necessary to have a list of errata of the errata; and in one instance there was an erratum of the errata of the errata.

In cases such as these the sources of error are so numerous that it is difficult to find a remedy for them all, so long as the common modes of calculating, transcribing, and printing are adopted. Some of these errors have been referred to false computation, others to inaccurate transcription; some have been referred to the compositor; others to a displacement of the types by the inking-ball used in the old method of printing, and the incorrect replacement of such types by the pressman.

The apparently hopeless task of preparing accurate tables by the common methods led Mr. Babbage, about thirty years ago, to consider whether a machine might not be constructed for computing and printing off mathematical tables. The proposed machine was to be capable not only of performing arithmetical calculations, but all those of mathematical analysis, provided their laws were known; and the principle upon which it was to depend was to be of so general a nature that, if applied to machinery, the latter might be capable of mechanically translating the operations indicated to it by algebraical notation.

Mr. Babbage's first attempts originated in the following circumstances. The French government, wishing to promote the extension of the decimal system, had ordered the construction of logarithmical and trigonometrical tables of enormous extent. M. le Prony, who directed the undertaking, divided it into three sections, to each of which was appointed a special class of persons. In the first section the formulæ were so combined as to adapt them to the purposes of numerical calculation; in the second, these same formulæ were calculated for values of the variable, selected at certain successive distances; and under the third section, comprising about 80 individuals, who were most of them only acquainted with the first two rules of arithmetic, the values which were intermediate to those of the second section were interpolated by means of simple additions and subtractions. The body of tables thus calculated consisted of 17 MS folio volumes. They have not been published. The printing was begun, and a small portion stereotyped, but a sudden fall in the value of assignats rendered it impossible for the printer to fulfil his contract with the government. The British government made an offer of 5,000*l.* towards the completion of the work; but political circumstances appear to have prevented its readoption, and it has never been resumed. A similar undertaking was, however, entered upon in England; and Mr. Babbage conceived that the operations performed under the third section might be executed by a machine, which he proposed to call the *Difference Engine*, on account of the principle upon which its construction is founded. Some notion of this will be gained by considering the series of whole square numbers,

1, 4, 9, 16, 25, 36, 49, 64, &c.

By subtracting each of these from the succeeding one, a new series is obtained, named the series of first differences, consisting of the numbers,

3, 5, 7, 9, 11, 13, 15, &c.

On subtracting from each of these the preceding one, we obtain the second differences, which are all constant, and equal to 2. This succession of operations and their results are represented in the following table:—

	A.	B.	C.
	Column of Square Numbers	First Differences	Second Differences
	1		
		3	
	4		2 *b*
		5	
a	9		2 *l*
		7	
c	16		2
		9	
	25		2
		11	
	36		

From the mode in which the columns B and C have been formed, it is obvious that if we wish to pass from the number 5 to the succeeding one 7, for example, we must add to the former the constant difference 2; so, also, if from the square number 9 we would pass to the following one, 16, we must add to the former the difference 7, which difference is, in other words, the preceding difference 5 plus the constant difference 2; or, what is the same thing, to obtain 16, we have only to add together the three numbers, 2, 5, 9, placed obliquely in the direction *a b*. So also we get the number 25, by summing up the three numbers placed in the oblique direction *b c*. Commencing by the addition 2 + 7, we have the first difference 9 consecutively to 7; adding 16 to 9, we have the square 25. Thus, the three numbers 2, 5, 9, being given, the whole series of successive square numbers, and also that of their first differences, may be obtained by means of simple additions.

Now, to reproduce these operations by means of a machine, suppose the latter to have three dials, A, B, C, on each of which are traced, say, 1,000 divisions, over which a needle shall pass; that the two dials C, B, have also a registering hammer, which is to give a number of strokes equal to that of the division indicated by the needle; that for each stroke of the registering hammer of the dial C, the needle B shall advance one division, and that similarly the needle A shall advance one division for every stroke of the registering hammer of the dial B. Such is the general disposition of the mechanism.

This being understood, suppose, at the beginning of the operations which are to be executed, we place the needle C on the division 2, the needle B on the division 5, and the needle A on the division 9. Allow the hammer of the dial C to strike: it will strike twice, and at the same time the needle B will pass over two divisions The latter will then indicate the number 7, which succeeds the number 5 in the column of first differences. If the hammer of the dial B be then allowed to strike, it will strike 7 times, during which the needle A will advance 7 divisions: these added to the 9 already marked by it will give the number 16, which is the square of the number consecutive to 9. If we now recommence these operations, beginning with the needle C, which is always to be left on the division 2, it will be seen that, by repeating them indefinitely, we may successively reproduce the series of whole square numbers by means of very simple mechanism. It would be quite impossible, however, to enter upon the details of the machinery, for the drawings of the various parts, constructed by Mr. Babbage, or under his direction, cover a space of 1,000 square feet

A most valuable feature intended to be introduced into this machine is the power of printing the tables as fast as it calculates them. This was proposed to be accomplished in the following manner:—When one of the dial wheels is in such a position as to indicate any particular figure of the table, some mechanism at the back raises a curved arm, containing several figure punches. A plate of copper is brought near the bent arm, and by a sudden blow an impression of the required figure is punched in the copper, and the figure so punched corresponds with that indicated on the dial. The plate is shifted from place to place, until it is punched all over with figures arranged in a tabular form. It is then used either as an engraved copper plate, and printed from in that form, or it may be used as a mould in the casting of stereotype plates of the tables, which may thus be multiplied in a permanent form without the slightest chance of an erratum being required.

A portion only of this machine has been completed; but this portion is capable of calculating to five figures and two orders of differences, and performs its work with absolute precision; but no portion of the printing machinery exists.

In 1843 an application was made to Government by the Trustees of King's College, London, to allow the engine as it existed to be removed to the museum of that institution. The request was complied with, and the engine enclosed within a glass case now stands nearly in the centre of the museum. Fig. 398, is a representation thereof, made from a drawing from the engine itself

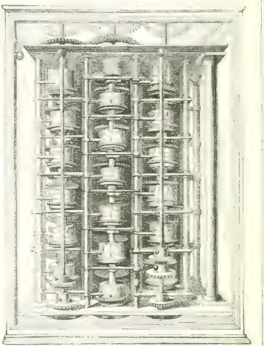


FIG. 398.—BABBAGE'S CALCULATING MACHINE.—THE DIFFERENCE ENGINE.

As this fragment of the difference-engine is public property, it will be interesting to state briefly the circumstances which have interfered with the completion of this great work of genius; and this we are enabled to do with the assistance of a chapter contained in the second Volume of Mr. Weld's "History of the Royal Society," (8vo. London, 1848,) which we understand received the sanction of Mr. Babbage himself, as a true and impartial statement.

It appears that on the 3d July, 1822, Mr. Babbage, in a letter to Sir Humphrey Davy, gave some account of a small model of his engine for calculating differences, which "produced figures at the rate of 44 a minute, and performed with rapidity and precision all those calculations for which it was designed. . . . . Induced by a conviction," says Mr. Babbage, "of the great utility of such engines, to withdraw for some time my attention from a subject on which it has been engaged during several years, and which possesses charms of a higher order, I have now arrived at a point where success is no longer doubtful. It must, however, be attained at a very considerable expense, which would not probably be replaced by the works it might produce for a long period of time, and which is an undertaking I should feel unwilling to commence, as altogether foreign to my habits and pursuits."

Early in April 1823, the Royal Society was requested by Government to take into consideration a plan which had been submitted by Mr. Babbage, for "applying machinery to the purposes of calculating and printing mathematical tables." A committee was accordingly appointed, and on the 1st May they reported, "that it appears that Mr. Babbage has displayed great talents and ingenuity in the construction of his machine for computation, which the Committee think fully adequate to the attainment of the objects proposed by the inventor, and that they consider Mr. Babbage as highly deserving of public encouragement in the prosecution of his arduous undertaking."

In consequence of this Report, the Lords of the Treasury directed the issue of 1,500*l.* to Mr. Babbage, to enable him to bring his invention to perfection. "Towards the end of July 1823, Mr. Babbage took measures for the construction of the present difference-engine, and it was regularly proceeded with for four years. And here it is right to state, that Mr. Babbage gave his mental labour gratuitously, and that from first to last he has not derived any emolument whatever from Government. Sectional and other drawings of the most delicate nature had to be made; tools to be formed expressly to meet mechanical difficulties; and workmen to be educated in the practical knowledge necessary in the construction of the machine. The mechanical department was placed under the management of Mr. Clement, a draughtsman of great ability, and a practical mechanic of the highest order. Money was advanced from time to time by the Treasury, the accounts furnished by the engineer undergoing the examination of auditors, and passing through the hands of Mr. Babbage. Thus years elapsed, and public attention became at length directed to the fact, that a large sum had been expended upon the construction of the engine which was not completed." In December 1828, Government requested the Council of the Royal Society to inquire into the state of the machine. A committee was accordingly appointed, and in their report they stated, that "the progress made was as great as could be expected, considering the numerous difficulties to be overcome, and that they had no hesitation in giving it as their opinion, that the engine was likely to fulfil the expectations entertained of it by its inventor." They further stated, that the public utility of the engine must be "obvious to all who consider the immense advantage of accurate numerical tables in all matters of calculation, which it is professedly the object of the engine to calculate and print with perfect accuracy."

This report was acted on by Government; funds were advanced, the machinery was declared national property, and the works were continued for a time; but the official payments soon failed to meet the expenses incurred. Accordingly a meeting of some of Mr. Babbage's personal friends took place on the 12th May, 1829, who drew up a report in which it was stated, "that Mr. Babbage's actual expenditure has amounted to nearly 7,000*l.*, and that the whole sum advanced to him by the Government is 3,000*l.* This report being submitted to Government, a further grant of 3,000*l.* was made towards the completion of the machine. Difficulties, however, of another kind arose. The engineer's bills to December 1830, amounting to nearly 7,200*l.*, had been delivered in such a state that it was impossible to decide how far the charges were just and reasonable. Mr. Maudslay, one of the engineers appointed by Government to examine Mr. Clement's bills, had been unable from illness to report thereon. An advance of 600*l.* was required to prevent Mr. Clement from discharging some workmen for want of funds. This was represented by Mr. Babbage to the Chancellor of the Exchequer, and it was also suggested, that as additional space was required for the erection of the machine, whether it would not contribute to its speed in completion and also to economy in expenditure, to remove the works to the neighbourhood of Mr. Babbage's own residence.

A committee of the Royal Society was again appointed to consider and report on these proposals. The Committee met Mr. Babbage at No. 21, Prospect Place, Lambeth, where the construction of the engine was carried on, and minutely inspected the machinery and drawings. The report stated that the various parts of the machine had been executed with the greatest possible degree of perfection, and that the pains taken to verify the charges on the part of the Government were altogether satisfactory. It was also recommended that the machinery and drawings be removed into fire-proof buildings without delay. A plot of ground held on lease by Mr. Babbage, adjacent to his garden at the back of his house in Dorset Street, was recommended as a desirable site for the contemplated buildings, of which the plans and erections had been submitted to the Committee. Mr. Brunel estimated that 8,000*l.* would be sufficient to defray the expenses, but he advised the sum of 12,000*l.* to be provided by way of estimate, and thought that the yearly sum required, exclusive of the sum requisite for the buildings and removal (say 2,000*l.*) would not exceed from 2,000*l.* to 2,500*l.*

This estimate was approved by a committee of practical engineers appointed by Government, and the recommendations were adopted. A fire-proof building was erected on the proposed site. New difficulties, however, arose. "When about 17,000*l.* had been expended, further progress was arrested on account of a misunderstanding with Mr. Clement, who made the most extravagant demands as compensation for carrying on the construction of the engine in the new buildings. These demands could not be satisfied with proper regard to the justice due to Government. Mr. Clement accordingly withdrew from the undertaking, and carried with him all the valuable tools that had been used in the work; a proceeding the more unfortunate, as many of them had been invented expressly to meet the unusual forms and combinations arising out of the novel construction.[1] An offer was made to surrender the tools for a given sum, which was declined, and the works came to a standstill.

During the suspension of the works, Mr. Babbage had been deprived of the use of his own drawings. In the meantime, however, having again considered the general principles on which machinery for calculation might be constructed, a principle of an entirely new kind occurred to him, the power of which over the most complicated arithmetical operations seemed almost unbounded. This was the executing of analytical operations by means of an *analytical engine.* In May 1835, Mr. Babbage, writing to M. Quetelet, says that for six months he had been engaged in making the drawings of a new calculating machine, of far greater power than the first. "I am myself astonished," says Mr. Babbage, "at the power I have been enabled to give this machine: a year ago, I should not have believed this result possible. This machine is intended to contain a hundred variables, or numbers susceptible of changing; and each of these numbers may consist of twenty-five figures. The greatest difficulties of the invention have already been surmounted, and the plans will be finished in a few months."

In a visit to Turin, Mr. Babbage explained to Baron Plana, M. Menabrea, and others, the mathematical principles of his analytical engine, and also the drawings and engravings of the contrivances by which those principles were to be carried out. M. Menabrea, with Mr. Babbage's consent, drew up an account of the analytical engine, which he published in the 41st volume of the *Bibliothèque Universelle de Genève.* An English translation, with copious original notes, made by Lady Lovelace, was published in the 3d volume of Taylor's *Scientific Memoirs,* (London, 1843.) From these notes the following passage is selected:—

"The distinctive characteristic of the Analytical Engine, and that which has rendered it possible to endow mechanism with such extensive faculties as bid fair to make this engine the executive right hand of abstract algebra, is the introduction into it of the principle which Jacquard devised for regulating, by means of punched cards, the most complicated patterns in the fabrication of brocaded stuffs. It is in this that the distinction between the two engines lies. Nothing of the sort exists in the Difference Engine. We may say most aptly that the Analytical Engine weaves algebraical patterns, just as the Jacquard loom weaves flowers and leaves. Here, it seems to us, resides much more of originality than the Difference Engine can be fairly entitled to claim. We do not wish to deny to this latter all such claims. We believe that it is the only proposal or attempt ever made to construct a calculating machine founded on the principle of successive orders of differences, and capable of printing off its own results; and that this engine surpasses its predecessors, both in the extent of the calculations which it can perform, in the facility, certainty, and accuracy with which it can effect them, and in the absence of all necessity for the intervention of human intelligence during the performance of its calculations. Its nature is, however, limited to the strictly arithmetical, and it is far from being the first or only scheme for constructing arithmetical calculating machines with more or less of success."

The state of the Analytical Engine at the time when Mr. Weld wrote his account (1848) was as follows:—"Mechanical notations have been made, both of the actions of detached parts and of the general action of the whole, which cover about four or five hundred large folio sheets of paper. The original rough sketches are contained in about five volumes. There are upwards of one hundred large drawings. No part of the construction of the Analytical Engine has yet been commenced. A long series of experiments have, however, been made upon the art of shaping metals; and the tools to be employed for that purpose have been discussed, and many drawings of them prepared. The great object of these inquiries and experiments is, on the one hand, by simplifying the construction as much as possible, and on the other, by contriving new and cheaper means of execution, ultimately to reduce the expense within those limits which a private individual may command."

Repeated applications to Government on the part of Mr. Babbage produced only this result:—that Government abandoned all further interference and assistance in the matter, and at the same time withdrew all claim to the machine as at present constructed, and it was placed at the entire disposal of Mr. Babbage. Considering, however, that the drawings and the parts of the machine already executed were paid for by the public money, Mr. Babbage declined to accept the offer; and it is greatly to be deplored that no further steps have been taken to carry out a scheme, the completion of which must be regarded as one of the glorious results of peaceful progress.

The reader who is desirous of further information on this subject will do well to consult the volume of Taylor's Scientific Memoirs already referred to. The accomplished author of the translation of M. Menabrea's memoir has given a list of most of the printed documents connected with the subject, up to the year 1843. [See APPENDIX.]

CALENDERING. A term said to be corrupted from *cylindering,* and signifying the finishing process in the manufacture of cotton or linen goods, by which they are passed between *cylinders* or rollers, and made of a level and uniform surface. When such goods

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(1) Mr Weld remarks, that Mr Clement had a legal right to the tools. "Startling as it may appear to the unprofessional reader, it is nevertheless the fact that engineers and mechanics possess the right of property to all tools that they have constructed, although the cost of construction has been defrayed by their employers."

have been bleached and washed, they are generally entangled and twisted, so as to be unfit for passing at once between the cylinders: they are therefore passed over the surface of a water cistern, kept constantly full, and as they thus make their way to the rollers, they unfold and accommodate themselves to the water, and are prepared as effectually as if by hand. But the action of the first pair of rollers does not spread or smooth the cloth effectually, neither does it dry it: it has, therefore, to be pulled out breadthwise, and the edges knocked against a smooth beating-stock. Pieces are also stitched together by a sailors' needle, to prepare them for the mangle. The domestic mangle will be noticed presently, but that used for calendering does not at all resemble it. It consists of a number of rollers, fixed in a strong upright frame; the rollers being forced together by levers, to which a considerable weight is attached, or by means of screws, as in Fig. 401. In some mangles the bottom rollers are grooved, the grooves gradually spreading from the right to the left on either side. The effect of this is to remove creases, by spreading out and extending the cloth as it passes between them. Above these are three smooth rollers, two of wood and one of brass, in passing between which the surface is equalized, and the cloth stretched. It is then wound upon a roller, ready to be starched.

The starch used in calendering is made from flour, deprived of gluten by fermentation in water, in the proportion of a pound of flour to a gallon of water. The whole is passed through a sieve after fermentation, and this separates the bran. The flour is then boiled, and a small quantity of indigo added, to give it a blue colour, after which more water is added, according to the degree of stiffness to be given to the goods. This liquid is frequently thickened with porcelain clay, or calcined plaster of Paris, or both, in order to give an appearance of strength and thickness to the cloth. This all disappears as soon as the goods are washed; therefore it merely makes them more attractive to the eye of the purchaser. The practice was originally deceptive; but it can scarcely be called so now that it is generally adopted, and is perfectly well known to the great majority of buyers

The method of applying the starch is by a stiffening mangle, formed of rollers of brass and wood pressed together by levers, the pressure being regulated by the quantity of starch required to be left in the material. The starch is contained in a trough, into which a roller dips, and the cloth in passing under this roller becomes filled with starch, the superfluous part of which is pressed out again by the upper rollers and falls back into the trough. The next operation is drying, which in the more substantial goods is effected by passing the goods over large tinned iron or copper cylinders, Fig. 399, heated by being filled with steam; but for muslins, the process merely consists of stretching out the material on long frames in a warm room. This is done with such celerity, that two young women can stretch a piece twenty-five yards long, and fasten it to the frame by pressing down numerous clamps prepared for the purpose, in the space of two minutes. The piece is then left [illegible] drying, and is then transferred to the making-up room. But in some cases it receives on the frames, what

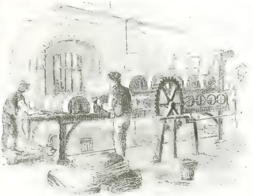


Fig. 399.—DRYING CYLINDERS.

is called the *patent finish*: that is, as soon as it is stretched, the two long sides of the frame are made to work backwards and forwards in opposite directions, giving the muslin a diagonal motion, which is continued till it is quite dry. The effect of this is to remove the harsh and stiff appearance which the starch would otherwise produce, and to make the muslin very clear and elastic. It has in fact the same effect as the beating and clapping of muslin articles by the laundress, in what is called clear-starching.

The finish for cotton goods often consists of a glazing, which is distinctively and especially known as calendering, and which gives a bright and beautiful gloss to the material. But this must first be damped by passing slowly over the *damper* or *damping machine*, containing a circular brush, the points of which as they rapidly revolve, just touch the surface of the water, and dash up a cloud of fine spray against the

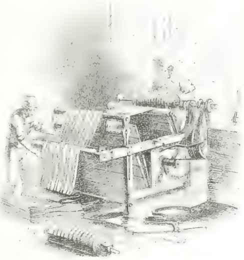


Fig. 400.—DAMPING MACHINE.

cloth. This being completed and the whole of the cloth uniformly damped, it now passes to the calendering machine, a number of rollers contained in a massive frame-work. The rollers are connected with a long lever loaded with weights at the further extremity, by which, or by means of screws as in Fig. 401, almost any amount of force may be obtained, and the surface texture of the cloth varied at pleasure. With considerable pressure between smooth rollers, a soft and silky lustre is given by the equal flattening of all the threads. By passing two folds at the same time between the rollers, the threads of one make an impression on the other, and [illegible] appearance with hollows between the threads. This may be varied at pleasure. It will be taken for granted by those who have never witnessed the operations, that the rollers are all of iron but this is not the case; they are of cast-iron, wood, paper, or calico, according to the uses for which they are designed. Great care is taken in the construction of the rollers, whatever the material, and those of paper are far from being so fragile as the nature of the substance would seem to imply, for they are in fact a mass of circular disks of pasteboard, threaded upon a square bar of wrought iron, and secured by iron disks at each end. These disks are screwed down tightly together, making a solid cylinder, which is placed in a stove and kept at a high temperature for several days to drive off all moisture, when the screws are tightened and the cylinder becomes remarkably dense and hard, so much so that, in being finished at a turning-lathe, it blunts all the tools employed, and requires two men to be kept constantly at work sharpening them. Copper embossed rollers are also kept in great variety for producing figures and patterns on velvet goods. The water surface is produced by passing the goods in a very damp state through the calender with hot or cold rollers, plain or indented, and sometimes with a slight lateral motion. The roller is heated by the insertion into it of a red hot cylinder. One of these embossing machines is shown in Fig. 402. From the great weight of calendering machines it is necessary that they should be fixed on the basement floor. After the cloth has received its final gloss at these machines, it is smoothly folded on a clean board, and taken to the making-up room to be measured preparatory to being rolled or folded for sale.

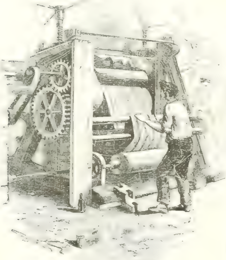


Fig. 401.—CALENDERING MACHINE.

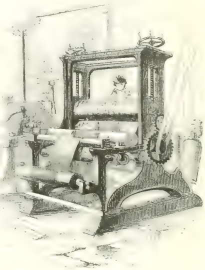


Fig. 402.—EMBOSSING MACHINE.

The calenderer usually undertakes many of the operations of packing, sheeting, and preparing goods for shipment. In order to suit the great extent and variety of manufacture in this country, and to adapt goods to the tastes or prejudices of an extensive range of customers, a multiplicity of foldings or lappings has been adopted. The objects proposed to be attained thereby appear to have been, 1. To preserve effectually the dressed surface of the goods from acute creases; 2. To imitate the external appearance of some descriptions of foreign goods; 3. To impart a peculiar external appearance to British goods,—an object which was further secured by stamping the words "British Manufacture" on the ends of the pieces, to show that they are home-made. In Irish cambrics and linens, a foreign fold has been adopted; the French flax, from superiority of climate and other causes, leading to the production of a superior fabric. Irish cambrics are therefore folded so as to imitate the French fold. The pieces, after being folded into lengths of about 12 inches, and twice laterally doubled, until the whole breadth of 34 inches is reduced to about 8½ inches, are powerfully compressed, until fully flattened. They are then packed in purple-coloured wrappers or papers, and a small engraved card or ticket is attached to each piece, stating the length, which is generally 8 or 8½ yards. As the importation of manufactured cambrics was illegal, the cards, in real French cambrics, were attached by a silken string, so as to be easily cut away, to avoid seizure. The same method was adopted with the Irish goods; and such is the unreasoning preference of many persons for goods of foreign manufacture, that cotton cambrics, essentially of British manufacture, came to be folded, papered, and ticketed, in precisely the same manner.

In linens, hollands, and sheetings, and also in cotton shirtings and sheetings, the foreign fold is that of a cylindric roll, somewhat flattened by subsequent compression, for the purpose of safety to the goods, and diminution in space in carriage. The Irish and British linens, &c., are made up in the same manner.

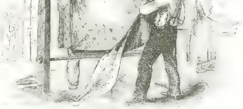
Cotton prints, and the extensive varieties of cotton cloths of British manufacture, are also lapped in imitation of the rude Indian method practised in Hindostan long before the art of calico-printing was known to us. The method is, to double a piece of 20 yards, to reduce its length to 10 yards, which by again doubling is reduced to 5; and in this way they continue to redouble until the piece is reduced to a moderate length, capable of being packed in a chest or bale.

British muslins are usually folded to a yard in length, with a small allowance for extra measure: the folding is alternately from right to left, so that every part can be opened and examined with ease, like the leaves of a book, before it is cut open. The piece, when folded, is reduced by doubling it lengthwise to about 19 inches, and it is then folded across the breadth of about 13 inches. An ordinary sized trunk, 39 × 19 inches, thus contains three layers of pieces, and it is stated that, in the colonies, trunks of this kind are as much in demand as the muslins contained in them. "Even the Indian ornaments of gilt silver threads, which were at first woven into one end of each piece, although they did not exceed the value of twopence each, have been either greatly curtailed or totally given up, upon principles of economy. Even the cost of this trivial ornament has been computed to have amounted annually in Glasgow and Paisley to about 30,000*l*." [1]

Some kinds of handkerchiefs are folded in dozens; but for the African and a few other markets they are made up in pieces containing only eight handkerchiefs. Indeed, so successful have been the imitations of Indian and other foreign goods, in texture, in dye, in pattern, in finishing, and in the package, that instances have occurred of seizure at the Custom-house, as India goods either illegally imported, or stolen from some of the Company's ships.

At Messrs. Goodier's calendering works at Manchester, the goods are measured, preparatory to being lapped or folded, either at a long table or at the hooking-frame. The measuring-table is a long smooth plank, with a scale of inches, feet, and yards marked at the side. A man stands at one end of the table, with the goods to be measured, and there is a boy at the other end. A length of cloth being spread out, the boy holds its extremity down at a line drawn on the table, while the man at his end marks a length of a certain number of yards, usually about five, with a piece of red or white chalk, according to the colour of the goods, the red being used for white stuffs. The boy then draws the cloth towards him, until the chalk-mark comes opposite to the line on the table, when he stops: the man then makes a second mark; the boy draws the length towards him until this mark arrives at the line, when the man repeats the mark, and so on until the proper length for a piece of goods is run off. Goods for the foreign market are measured by what is called *short stick;* those for the home market by *long stick*. In short stick, the yard is made to consist of "35 inches and a thumb," which is, in fact, 36 inches, the usual length of the yard, or it may be a trifle more. In long stick, the yard contains "36 inches and a thumb," which is equivalent to 37 inches. There is [illegible], containing "35½ inches and a thumb" to the yard, and this is equal to 36½ inches.

The measuring-table is used chiefly for goods that are made up [illegible], the hooking-frame, Fig. 403, is used. This consists of



[illegible]

an iron bar, rather more than four feet long, graduated into inches and parts, supported by a wooden frame, and capable of being raised to different heights. At one extremity of the bar is a projecting needle, which is fixed; a second needle, attached to an iron slide, can be moved along the bar, and fixed at any point by means of a screw. The length of the yard varies at the hooking-frame as at the measuring-table. This length being determined for the goods to be measured, the children who act as hookers hang the cloth in regular folds upon the hooks, until a sufficient quantity is collected to form a piece, which is then cut off and removed, to be made up.

There are upwards of a hundred different methods of making up goods, and each method has its own particular name, such as the *falling lap*, the *Wigan lap*, the *[illegible] lap*, the *Pr[illegible]*, &c. Muslin, as already noticed, is made up in *book-fold*, in pieces of 24 yards; but usually two half-pieces, called *demis*, are made up in one book, with yellow paper under the first fold, to show the pattern, and the corners are secured with variegated silk thread. Tickets,

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(1) Encyclopædia Britannica, Art. *Calender*.

containing various devices in gold or bronze, upon a blue or red ground, are pasted upon each piece, varying according to the market. Some of these tickets are of large size, and very costly; those printed in gold varying from 15s. to 25s. per 100, while the common forms of labels may be had for 2*s.* per 1,000. The devices on these tickets are as various as their appearance: they may contain the name, or the crest, or the coat of arms of some Portuguese or Greek merchant, or mottoes in various languages of Europe or of the East, naming the goods, or assigning some excellent qualities to them.[1]

A notice of calendering would not be complete without a description of the *common domestic mangle.* This, though very inferior to the machines described above, is yet a useful means of improving the surface of linen, and approaches in its results the more perfect operations of the calendering machine. It is simply an oblong wooden chest filled with stones, resting upon two cylinders which roll backwards and forwards over the linen, spread upon a polished table beneath. Formerly the chest was moved by means of a handle attached to an upper roller or windlass, to which straps from each end of the chest were attached. In this case the linen was wrapped round the cylinders, and the motion of the chest had frequently to be arrested and changed. This was laborious work, and it was a valuable improvement when a continuous motion of the handle in one direction would effect the object, and when a fly-wheel was added to equalise the motion. This was first done by Mr. Baker of Fore Street, London, whose plan was subsequently improved upon by Mr. Elisha Peechey, who received a silver medal from the Society of Arts on account of it in 1823. His mangle is represented in Fig. 404. F F is a frame of cast-iron with cross pieces and bridges to support the handle; P the cast-iron box, filled with large stones and gravel to give it weight; R, the rack, which is made to move up and down at each end in projecting grooves or slit pieces, as represented at S, and attached to vertical plates V V rising from the box. This rack is a stout metal bar, with a row of pegs along the middle of one side; and parallel with the line of these pegs projects a deep margin, intended to confine a pinion to its hold upon the pins while moving the rack backwards and forwards, by acting successively on each side of the series of pins. H is the handle, and W the fly-wheel fixed on the opposite end of the arch adjoining the centre of the fly-wheel, which, acting upon a circle of cogs, gives revolution to the pinion which carries the rack, and the upper part of which is seen in the figure; P P are two iron prongs, either of which, on being turned down, lifts up and sustains the mangle-box when the rollers L L are to be taken out. Fig. 405, will show the manner in which the rack is balanced so as to produce the reciprocating motion. The rack being attached by each end to the connected levers, and counterpoised by the weights inside the mangle-box, the pinion traverses the row of pegs along the middle. When the pinion by the movement of the rack from right to left passes round the endmost peg, the rack will be lifted up, the weights in the box will sink, and the course of the pinion will be along the under side of the rack, until, on arriving at the last pin of the opposite end, the rack will again sink, the counterpoise rise to its present position, and the motion of the box be reversed with every alternation of the rack.

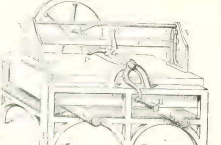

Fig. 404.

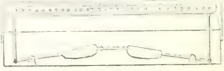

Fig. 405.

Various other patents have been taken out from time to time, several of which have been for vertical mangles, but although these occupy much less space than the common horizontal kind, yet they have never been in equal favour. Wilkinson's, otherwise known as Bullman's Cabinet Mangle, is one of the most efficient of the vertical kind.

CALICO. See COTTON.

CALICO-PRINTING. The art of producing a coloured pattern on cloth by the application of colouring substances appears to be of great antiquity. Homer notices the variegated linen cloths of Sidon as magnificent productions, and Herodotus says that the inhabitants of Caucasus adorned their garments with figures of animals, by means of an infusion of the leaves of a tree, and that the colours thus obtained were durable. Pliny's description of the art as practised by the ancient Egyptians, is almost identical with the modern processes. He says:—"They take white cloths, and apply to them not colours, but certain drugs which have the power of absorbing or drinking in colour; and in the cloth so operated on, there is not the smallest appearance of any dye or tincture. These cloths are then put into a cauldron of some colouring matter, scalding hot, and after having remained a time, are withdrawn all stained and painted in various colours. This is, indeed, a wonderful process, seeing that there is in

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(1) In this article the Editor has availed himself of some of the information collected during a visit to Manchester, and published in a work by him, entitled, "The Useful Arts and Manufactures of Great Britain," 2 vols. 12mo. [illegible] Published under the direction of the Committee of General Literature and Education appointed by the Society for Promoting Christian Knowledge.

the said cauldron, only one kind of colouring material; yet from it the cloth acquires this and that colour, and the boiling liquor itself also changes according to the quality and nature of the dye-absorbing drugs which were at first laid on the white cloth. And these stains or colours, moreover, are so firmly fixed as to be incapable of being removed by washing. If the scalding liquor were composed of various tinctures and colours, it would doubtless have compounded them all in one on the cloth; but here one liquor gives a variety of colours according to the drugs previously applied. The colours of the cloths thus prepared are always more firm and durable than if the cloths were not dipped into the boiling cauldron." In India the art of calico-printing has been practised for ages, and it derives its English name from *Calicut*, a town in the province of Malabar, where it was formerly carried on extensively. The large cotton chintz counterpanes, called *pallampoors*, which from an early period have been made in the East Indies, are prepared by placing on the cloth a pattern of wax, and dyeing the parts not so protected. Cortez noticed in Mexico that the inhabitants wore garments ornamented with coloured figures. The North American Indians have also been long acquainted with the art of applying different coloured patterns to cloth.

The art of calico-printing was practised in Asia Minor and the Levant several centuries before its introduction to Europe. It was not till the close of the seventeenth or the beginning of the eighteenth century that Augsburg became celebrated for its printed cottons and linens, and that city was long a school for the manufacturers of Alsace and Switzerland. The art was introduced into England, about the year 1676, by a Frenchman, who established works on the banks of the Thames, near Richmond. More extensive works were established soon after at Bromley Hall, in Essex. About the year 1700, the calico-printers were unexpectedly benefited by an act passed at the urgent solicitation of the silk and woollen weavers, to prohibit the importation of chintzes from India; whereupon several print-works were established in Surrey for the purpose of supplying imitations of these goods, which, as the silk and woollen weavers declared, had prevented their trades from thriving. The chintzes were produced by printing white Indian calicoes, the import of which was still allowed on payment of a duty. In 1712, a duty of 3*d*. per square yard was imposed on this printed calico, which two years after was doubled; but as the importation of white calico was scarcely checked by these harsh and unwise measures, the clamours of the silk and woollen weavers became louder, and the Government actually passed an act prohibiting the wearing of all printed calico, under a penalty of 5*l*. for each offence on the part of the wearer, and of 20*l*. on the seller.[1] In consequence of this law, the operations of the printer were confined to the printing of linen until the year 1730, when calico was again allowed to be printed, provided the warp was of linen, and the weft only of cotton; and even then it was subject to a duty of 6*d*. per square yard. With such impediments the process of the art was of course slow. In the middle of the last century only 50,000 pieces of the mixed cloth were printed each year in Great Britain, whereas, at the present time, a single manufactory will turn out six or eight times that quantity in the course of a year. About the year 1774, when Arkwright's machinery was producing calico with such wonderful facility, the legislature repealed the unjust law which prohibited the wearing of printed calico made entirely of cotton, imposing, however, upon it a duty of 3*d*. per square yard, which was raised in 1806 to 3½*d*.

As printed calicoes and cottons formed an important article of dress with nearly all classes of the community, especially the lower, the continuance of this heavy duty was felt to be a great hardship, and interfered also with attempts to improve the art. Moreover, the actual revenue obtained from this source was but small, after deducting drawbacks on exports, and the expenses of collection. Thus in the year 1830, a revenue of 2,280,000*l*. was levied on 8,596,000 pieces, of which, however, about three-fourths were exported with a drawback of 1,579,000*l*., and deducting the expenses of collection, the sum of 350,000*l*. only found its way into the exchequer. In the year 1831, the duty was wholly repealed, to the great advantage both of manufacturer and consumer; and since that time the art has been carried to a wonderful state of perfection, both chemically and mechanically. Printed goods which half a century ago were sold for 2*s*. 3*d*. per yard, may now be had for 8*d*. or less; and a cotton print, sufficient for a complete dress, may be had for 3*s*. or 4*s*., or less. It is stated by Mr. M'Culloch, as an example of the prodigious increase of calico-printing, that in 1829, before the abolition of the duty, 89,862,433 yards of all descriptions of printed goods were exported; whereas in 1841, there were exported of printed cottons alone 329,240,892 yards, of the declared value of 7,772,735*l*.

The object of calico-printing is to apply one or more colours to particular parts of cloth, so as to represent a distinct pattern, and the beauty of a print depends on the elegance of the pattern, and the brilliancy and contrast of the colours. The processes employed are applicable to linen, silk, worsted, and mixed fabrics, although they are usually referred to cotton cloth, or calico.

There are various methods of calico-printing, the simplest of which is block-printing by hand, in which the pattern or a portion thereof is engraved in relief upon the face of a block of sycamore, holly, or pear-tree wood, backed with deal, and furnished with a strong handle of box-wood. The block, Fig. 406, varies in size from 9 to 12 inches long, and from 4 to 7 inches broad. In

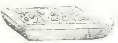

Fig. 406.

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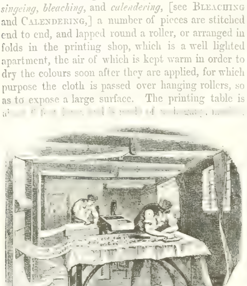
[1] An act was also passed in the same year, [illegible] George I., prohibiting the wearing of buttons or button-holes made of cloth, the object being to encourage the use of silk.

some cases the pattern is formed by the insertion into the block of narrow strips of flattened copper, the interstices being filled with felt. This gives a very distinct impression. The block is charged with colour by pressing it upon a surface of woollen cloth stretched tightly over a wooden drum. This, which is called the *sieve*, is made to float in a tub of size or thick varnish, for the purpose of giving it elasticity. The sieve is covered with the colouring matter by a child called the *tearer*, (probably from the French *tireur*,) who takes up with a brush a small quantity of the colour from a pot, and spreads it uniformly over the surface of the sieve, and every time that the man presses his block upon the sieve in order to charge it with colour, it is the duty of the tearer to brush over the woollen surface in order to erase the mark of the block, for if this were not done, the block would not be equally charged with colour.

The calico having been prepared for printing by *singeing*, *bleaching*, and *calendering*, [see BLEACHING and CALENDERING,] a number of pieces are stitched end to end, and lapped round a roller, or arranged in folds in the printing shop, which is a well lighted apartment, the air of which is kept warm in order to dry the colours soon after they are applied, for which purpose the cloth is passed over hanging rollers, so as to expose a large surface. The printing table is a[illegible] or [illegible] a flat hard surface. This table is covered with a blanket, upon which the calico is spread, and the block being charged with colour as above described, the man applies it to the cloth in the exact spot required, and in some cases strikes it on the back with a wooden mallet, in order to transfer the impression fully. Thus by repeated applications of the block, a pattern is produced in one colour. Care is required to place the block in the exact spot, so as to make one impression exactly join or fit in with the previous impression, and for this purpose the block is furnished with small pins at the corners, which make holes in the cloth, and serve as a guide to the printer. If the pattern contain three or more colours there must be as many blocks, all of equal size, the raised portions in one, which take up colour, corresponding with depressed portions in the others which do not take up colour. In order therefore to print a piece of cloth 28 yards long, and 30 inches broad, with three blocks, each measuring 9 inches by 5, there must be 672 applications of each.[1] But if the design consist of parallel stripes of different colours, they may be applied with one block at a single application on the same part of the cloth, by arranging the colours in small tin troughs, and transferring a portion from them to the sieve by means of a small wire brush, and the colour is then distributed evenly in stripes over the surface by a roller covered with woollen cloth. In those patterns in which the colours are blended into one another at the edges, in what is called the *rainbow style*, they are first blended by a brush on the sieve before being taken up by the block. Stereotyping has been applied to the production of printing blocks. A small mould is produced from a model of the pattern, and copies are then made by pouring fusible metal into it. [See BISMUTH.] A number of these plates are joined together, and mounted in a stout piece of wood, and thus form a printing-block.



[illegible]

A machine called the *Perrotine*, in honour of its inventor M. Perrot of Rouen, is in use in France and Belgium as a substitute for hand-block printing. It is thus described by Dr. Ure:—"Three wooden blocks, from $2\frac{1}{2}$ to 3 feet long, according to the breadth of the cloth, and from 2 to 5 inches broad, faced with pear-tree wood, engraved in relief, are mounted in a powerful cast-iron frame-work, with their planes at right angles to each other, so that each of them may, in succession, be brought to bear upon the face, top, and back, of a square prism of iron covered with cloth, and fitted to revolve upon an axis between the said blocks. The calico passes between the prism and the engraved blocks, and receives successive impressions from them as it is successively drawn through by a winding cylinder. The blocks are pressed against the calico through the agency of springs, which imitate the elastic pressure of the workman's hand. Each block receives a coat of coloured paste from a woollen surface, smeared after every contact with a mechanical brush. One man with one or two children for superintending the colour-giving surfaces, can turn off about 30 pieces English per day, in three colours, which is the work of fully 20 men and 20 children in block printing by hand."[2]

Copper-plate printing similar to that used in the production of engravings has also been applied to calico-printing, but the perfection to which cylinder-printing, next to be described, has been brought, rendered the extension of this method unnecessary.

The invention of *cylinder* or *roller-printing*, is the

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(1) Fig. 47 shows the general arrangements of the printing-room in printing by hand. At the time our artist made this sketch, the printers were working in the *discharge style* (which will be noticed further on); the acid used to discharge the colour is supplied to the sieve by means of an inverted bottle, as shown in the cut, so that the services of the tearer are not required.

(2) Dictionary of Arts, Manufactures and Mines, Article "Calico Printing."

greatest achievement that has been made in the art, producing results which are truly extraordinary: a length of calico equal to one mile can by this method be printed off with four different colours in one hour, and more accurately and with better effect than block printing by hand. One cylinder machine, attended by one man, can perform as much work in the same time as 100 men attended by 100 tearers. The effect of this beautiful machine has been greatly to cheapen cotton prints, and to create an enormous demand for them, both for the home and the export trade, so that while apparently superseding labour in one direction it creates a demand for it in all directions.

The invention of this machine is attributed to two persons who had no connexion with each other: the one is a Scotchman named Bell, who about the year 1785 practised at Monsey near Preston; the other was named Oberkampf, a calico printer at Jouy in France. We will endeavour, with the assistance of a diagram, to explain the principle of the machine as arranged for printing a pattern in three colours. The cylinders upon which the pattern is engraved, one cylinder for each colour, are shown in section at c c c, Fig. 208, and a view of one of them in Fig. 209. Each cylinder is mounted on a strong frame-work, so as to revolve against two other cylinders D and e: the cylinder e is covered with woollen cloth, and dips into a trough i, containing the colouring matter properly thickened, so that as e revolves it takes up a coating of colour and distributes it over the engraved roller c. D is a large iron drum covered with several folds of woollen cloth, so as to form a somewhat elastic printing surface; an endless web of blanketing a a is made to travel round this drum, which serves as a sort of guide, and defence, and printing surface to the calico b b which is being printed. Now it is obvious from this arrangement, that the cylinder e in revolving must spread the colour uniformly over the engraved cylinder c, whereas it is wanted only in the depressed or engraved parts; the excess of colour has therefore to be removed before the roller comes in contact with the calico, or instead of being ornamented with a pattern it would be disfigured with an unmeaning patch of colour. The superfluous colour is removed by a sharp edged knife or plate d, usually of steel, called the *doctor*.[1] This is so arranged that the colour scraped off shall fall back into the trough i. Each engraved cylinder is usually provided with two doctors, one called the *colour doctor*, d, and the other the *lint doctor*, d′. The object of the latter is to remove the fibres which the roller acquires from the calico. Doctors are made of gun-metal, bronze, brass and iron alloys, as well as of steel, that metal being used which is least acted on by the colouring materials and mordants used in the process.

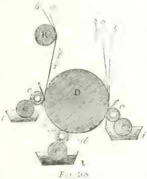

Fig. 208.

Fig. 209.

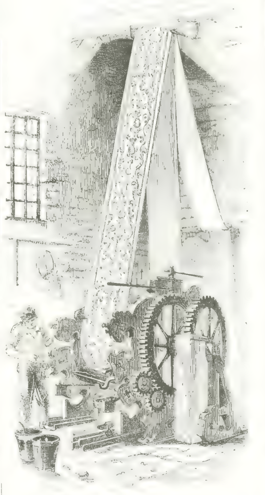

Fig. 210. Cylinder Printing Machine.

Fig. 210 is a view of a cylinder machine for printing colours. It has been engraved from a sketch made by Mr. Prior, in the well arranged print-works of Mr. Joseph Lees of Manchester, who kindly allowed the Editor and the Artist to examine all the processes in detail. Some of the machines are very complicated in appearance, as many as eight colours being printed at once by one machine; but this complication is only apparent, for it is produced by the repetition of similar arrangements eight times over, each engraved roller, provided with its own colour trough, &c., revolving against the iron drum B; but very great nicety of arrangement is required to bring all these rollers to bear upon the cloth, so as to print at the exact spots required for forming a complicated pattern; but when the proper adjustment is made, a machine for printing eight colours acts with as much precision and regularity as a machine arranged for a fewer number of colours.

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[1] The origin of this term has been explained by Mr. Baines in his History of the Cotton Manufacture. When Mr. Hargreaves, a partner in the factory at Monsey near Preston, where cylinder printing was first introduced, as already noticed, was making some experiments with the machine, one of his workmen said, "All this is very well, Sir, but how will you remove the superfluous colour from the surface of the cylinder?" Mr. Hargreaves took up a common knife, and pressing the edge parallel with the axis of the revolving cylinder, at once showed its action in removing the colour. After a moment's pause the workman exclaimed, "Oh sir, you have doctored it!" [illegible] "You have doctored it," and the contrivance has ever since retained the name of the doctor. Another explanation is that the word doctor is a corruption of the ductor, [illegible]

As fast as the calico is printed, it is drawn through a long gallery or passage, raised to the temperature of nearly 200°, by means of a furnace flue which traverses its whole length. The upper surface of the gallery is covered with rough plates of cast-iron which radiate heat upon the printed goods. A piece of calico of 28 yards is drawn through the gallery in about two minutes, during which the colours become dried and set.

The printing cylinders vary in length from 30 to 40 inches, according to the width of the calico: the diameter varies from 4 to 12 inches. Each cylinder, A, and in section C, Fig. 411, is bored through the axis *d d*, and accurately turned from a solid piece of metal. For some styles of pattern the engraving is done by hand, but as this is expensive, it is usual to adopt Perkins's method of transferring engravings from one surface to another by means of small steel rollers, B. The pattern is first drawn upon a scale of about 3 inches square, so that this size of figure being repeated a number of times will cover the printing cylinder. The pattern is then engraved upon a roller of soft steel about 1 inch in diameter, and 3 inches long, so as to occupy its surface exactly. This small roller, which is called the *die*, is next hardened by heating it to redness and suddenly quenching it in cold water. The roller thus hardened is then put into a rotatory press, and made to transfer its design to a similar small roller in a soft state, called the *mill*. The design which was sunk in the die, now appears in relief on the mill. The mill in its turn is hardened, and being put into a rotatory press, engraves or indents upon the large copper cylinder the whole of the intended pattern. This is of course a work of time, and requires considerable care to make the numerous junctions of the small roller exactly fit each other upon the printing cylinder. By this process, however, a pattern may be imparted to a large cylinder at the cost of about 7*l*., while if engraved by hand it might cost seven or eight times that sum. By the method just described, a worn cylinder can be renewed and made equal to a new one.—The pattern is also sometimes produced by *etching*, in which case the cylinder is covered with a thin coat of varnish, and on this the pattern is traced with a diamond or steel point. Aqua-fortis is then applied to the surface, which bites into or corrodes the parts which have been removed by the point. This point or tracer is sometimes applied in a manner similar to that of the eccentric chuck of a lathe, by which means the surface is covered with patterns, or a ground-work for patterns of great variety and beauty. Eccentrically engraved cylinders are exported from Manchester, and the foreign printer adds the pattern. The cost of a copper cylinder before engraving, varies from 5*l*. to 7*l*., and the cost of engraving from 5*l*. to 10*l*.—The electrotype has also been used for producing the design on the printing cylinder.—The design is also sometimes cut in relief upon wooden rollers; or formed by the insertion of flat pieces of copper edgeways. This is termed *surface printing*, probably from the circumstance of the thickened colour being applied to a tense surface of woollen cloth, against which the cylinder revolves and takes up colour. A combination of wooden and copper rollers forms what is called the *union printing-machine*.

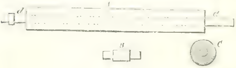


Fig. 411

Another method of calico-printing remains to be described, namely, *press-printing*, by which several colours can be printed at once. The cloth to be printed is wound upon a roller at one end of the machine, and the design, which is formed in a block of mixed metal about $2\frac{1}{2}$ feet square, is supported with its face downwards in an iron frame, and can be raised or lowered at pleasure. The face of the block is divided into as many stripes, ranging crossways with the table, as there are colours to be printed. If, for example, the pattern be made up of five stripes of different colours, and each stripe be 6 inches broad, and as long as the breadth of the cloth, the colours have to be applied without mingling or interfering with each other. This is accomplished in the following manner:—The side edges of the table are furnished with a couple of rails similar to a railway, and upon this is a shallow tray or frame, capable of moving backwards and forwards upon wheels. Within this frame is a cushion of about the same size as the printing-block, and by its side are five small troughs containing the thickened colours. By means of a long piece of wood, formed so as to dip into all the troughs at once, the tearer applies a small portion of each colour to the surface of the cushion, and spreads them evenly into five portions or stripes, taking care not to mix them; but making their breadth equal to that of the stereotype rows on the block. The cushion being prepared, the frame is rolled along the railway until it is immediately under the printing-block, which the pressman then lowers upon the cushion, by which means the five stripes of the block become charged, each with its proper colour. The block is then raised, the frame rolled away, and the block brought down upon the cloth, which it prints with five rows of different colours. On raising the block, the cloth is drawn forward about six inches in the direction of its length, or exactly the width of one stripe on the block; the tearer again pushes forward the cushion with the colours renewed, and the block is again charged and applied to the cloth. Now, as a length of the cloth equal to the width of a stripe is drawn from under the block at each impression, every part of the cloth is brought into contact with all the stripes on the block. Great care is required so to adjust all the moving parts of the press, that the colours may not mingle, and distort the pattern.

Having thus briefly described the chief mechanical processes of calico-printing, we come now to notice the chemical. The colours used in calico-printing are derived from all the three kingdoms of nature, but it seldom happens that solutions, infusions, or decoctions of these colours admit of being applied at once to the cloth without some previous preparation, either of the cloth itself, or of the colouring material. It is often necessary to apply some substance to the cloth which shall act as a bond of union between it and the colouring matter. This substance is usually a metallic salt, which has an affinity for the tissue of the cloth as well as for the colouring matter when in a state of solution, and forms with the latter an insoluble compound. Such a substance is called a *mordant*, (from the Latin *mordere*, to bite,) a term given by the French dyers under the idea that it exerted a corrosive action on the fibre, expanding the pores, and allowing the colour to be absorbed. The usual mordants are common alum and several salts of alumina, peroxide of iron, peroxide of tin, protoxide of tin, and oxide of chrome. These have an affinity for colouring matters, but many of their salts have also a considerable attraction for the tissue of the cloth, which withdraws them to a certain extent from their solutions. Mordants are useful for all those vegetable and animal colouring matters which are soluble in water, but have not a strong affinity for tissues. The action of the mordant is to withdraw them from solution, and to form with them, upon the cloth itself, certain compounds which are insoluble in water.

In calico-printing it is generally necessary to bring the mordant or the colouring matter into such a state of consistency as to prevent it from spreading beyond the proper limits of the design. This is done by the use of *thickener*, the most useful of which is wheat-starch, and flour; but many others are used, such as gum-arabic, British gum, high-dried potato starch, gum-Senegal, gum-tragacanth, jalap, pipe-clay, or China-clay mixed with gum, dextrine, potato and rice starch, sulphate of lead mixed with gum, and many others. The choice of proper thickeners requires attention; for two similar solutions of the same mordant equally thickened, but with different thickeners, may give different shades of colour when used with the same colouring material.

The colours, with the proper thickeners, &c. are prepared in vessels furnished with steam-jackets, as shown in Fig. 112, for raising the contents to the required temperature.

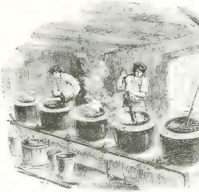


Fig. 112. [illegible]

Although the different methods of printing are numerous, and the combinations of colours and shades of colour almost infinite, yet each colour in a pattern must, in the present state of the art, be applied by one of six different *styles* of work. These are termed, 1, the Madder style; 2, Printing by steam; 3, the Padding style; 4, the Resist style; 5, the Discharge style; and 6, the China-Blue style. By the proper combination of two or more of these styles any pattern however complicated is produced.

The madder style is so called from its being chiefly practised with madder; but it is applicable to most soluble vegetable and animal colouring matters. The first process in this style is to print the calico with a mordant; that is, instead of printing at once with colour, the parts of the surface which are to have a madder colour imparted to them, are first impressed with a mordant. After the calico has passed through the hot flue, it is in many cases suspended free from folds for one or two days in what is called the *ageing-room*, where by exposure to air the mordant, or a portion thereof, undergoes a chemical alteration, whereby it becomes attached to the cloth in an insoluble state. Any portion of the mordant that remains in a soluble state must be completely removed, or the colour in being subsequently applied would spread over the surface, instead of being confined within the limits of the pattern. The superfluous mordant is removed by passing the dried calico through a warm mixture of cow-dung and water. This is called *dunging*. The mixture is usually contained in two stone cisterns, placed end to end, each about 6 feet long, 3 feet wide, and 4 feet deep. The mixture in one cistern is formed with about 2 gallons of dung to the cistern full of water, heated to about 160° or 180°. The second cistern contains about half this quantity of dung. The calico, guided by rollers to keep it free from folds, is drawn quickly through the first trough, and then immediately through the second. It is then washed in clean water in what is called a wince-pit, and again in a dash-wheel. [See BLEACHING.] Dunging is further useful in removing the thickening paste by which the mordant is applied, and it also determines a more intimate union between the mordant and the fibre of the cloth. The process is necessary for alum, iron, and tin mordants, when applied to the cloth before the colouring matter.

The difficulty of procuring cow-dung in sufficient quantities has led to attempts to find substitutes in those chemical substances which an analysis of dung indicate as the essential ingredients. Thus a solution of phosphate of soda and phosphate of lime, with a little glue or some other form of gelatine, has been used under the name of *dung-substitute*, or simply *substitute.*

After washing in cold water, the mordanted cloth is winced in a weak solution of substitute and sise. It is then ready for the colour. This is not applying by the process of printing, but simply by drawing the cloth for two or three hours through a solution of the colouring material. [See DYEING.] The colour attaches itself permanently to those portions of the cloth to which the mordant has been applied, and forms a true chemical compound therewith; but on the unmordanted portions the colour is feebly attached, and is subsequently removed by washing in soap and water, or in bran and water, or in a dilute solution of chloride of lime. This last washing is called *clearing.*

Such is a very meagre outline of the most important processes concerned in printing and dyeing a piece of calico according to the madder style. The processes actually required for finishing a piece of cloth are numerous, as for example, in producing a red stripe upon a white ground, the bleached cloth is submitted to nineteen operations, as follows:—1. Printing on mordant of red liquor, (a preparation of alumina,) thickened with flour, and dyeing; 2. Ageing for three days; 3. Dunging; 4. Wincing in cold water; 5. Washing at the dash-wheel; 6. Wincing in dung-substitute and sise; 7. Wincing in cold water; 8. Dyeing in madder; 9. Wincing in cold water; 10. Washing at the dash-wheel; 11. Wincing in soap-water containing a salt of tin; 12. Washing at the dash-wheel; 13. Wincing in soap-water; 14. Wincing in a solution of bleaching-powder; 15. Washing at the dash-wheel; 16. Drying by the water extractor; [See DYEING.] 17. Folding; 18. Starching; 19. Drying by steam.

The operations of washing and drying are very important, and provision is made for them on a very complete scale. Fig. 413 is a view of the washing and drying apparatus at Mr. Lees's works. The pieces of cloth are brought down into water-tanks, passing under and over rollers, furnished with balance-weights to keep the calico stretched: these weights can be adjusted on their levers, so as to vary the tension to any degree required. In some cases the bottom of the tank is supplied with water in jets, so that the calico is subjected to the dashing action of the water. In passing out of the washing machine, the calico is received on a skeleton roller, where it is smoothed by an attendant, and passes from this to the drying cylinders, Fig. 413, (see also Fig. 399,) and in section in Fig. 414, where the arrow on the left shows the calico proceeding from the washing-machine, passing over a guide roller R, and then over the drying cylinders, which are of metal, and heated by steam. It is then guided by a second roller R to the drum D, on which it is finally wound.

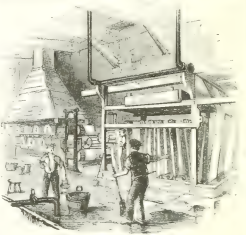


Fig. 413.—Washing Machine.

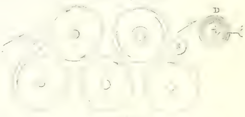
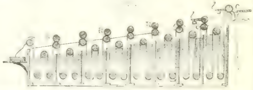


Fig. 414.

Another form of washing-machine is shown in section, Fig. 415. The cloth is arranged in folds upon a shelf to the left of the machine, whence it is guided by rollers into the first vat or division of the machine: it then passes out between rollers, R, which press out the water, and thus make it again absorbent, before passing into the second division: it proceeds in this way until it arrives at the seventh division, where the rollers are pressed together with weighted levers, *l* c, and the calico leaves the machine with most of its moisture pressed out. The object of having the divisions of unequal height is to establish a current of water; for the tallest vat being first supplied, overflows into the next, and this into the third from the right, until the collected overflowings escape by the lowest vat. In this way a current is kept up, and the calico, moving in a contrary direction to that of the current, is completely washed.



The second style of calico-printing is by steam. The colours which attach themselves firmly to the cloth by being printed on it with a mordant are not numerous, but by exposing the goods so printed to the action of steam, an intimate combination takes place between the tissue, the colouring matter, and the mordant. The mechanical arrangements for steaming are various. In some works the cloth is suspended free from folds in a small chamber of masonry, into which steam is admitted. In other works the goods are placed in a large deal box, the lid of which is made nearly steam-tight by edges of felt, and the steam is admitted through a pipe perforated with a multitude of small holes, which traverses the box. But the common method, Fig. 416, is to coil the calico round a hollow copper cylinder, A, perforated with holes, the lower end of which is connected with a steam-pipe. The cylinder is prepared by mounting it in a horizontal position in a frame. A roll of blanket is first lapped round it, then a piece of white calico, and lastly, three or four pieces of the printed and dried calico stitched end to end. The cylinder is then fixed upright in a small apartment furnished with a chimney to carry off the steam. The open end of the cylinder is screwed to a pipe connected with the spheres S, S, which are supplied with steam from the main boiler of the works, the quantity being regulated by a stop-cock C. The temperature is kept at 211° or 212° to prevent much condensation, which makes the colours run. A higher temperature is injurious, but a slight condensation is required to keep the goods moist. The steaming is carried on for from 20 to 40 minutes, according to the nature of the colour. When the steam is cut off, the cloth is unrolled immediately, to prevent condensation. On exposure to the air, the thickening material soon solidifies, and the goods become dry and stiff. The cloth is then aged for a day or two, and the thickener gently washed out with cold water.

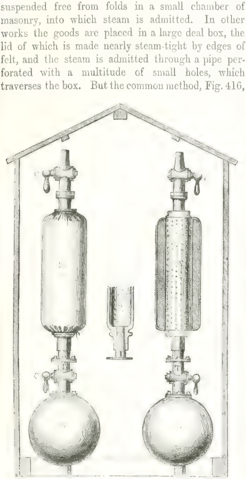


Fig. 416.—STEAMING APPARATUS.

The operation of steaming not only attaches the colour firmly, but gives it brilliancy and delicacy of finish. It is not always adopted, for some colours become firmly attached to the cloth by mere exposure to air. A variety of cheap goods for some of the foreign markets are printed in *fugitive* colours; these not being fixed by steaming or by a mordant are called *spirit*, *fancy*, or *wash-off* colours.

The third style, called the *padding style*, applies to mineral colours only. By this style a pattern may be produced on white or coloured ground, and a ground may also be formed for the design in other colours. For the latter purpose the *padding machine* is used. This is almost identical with the starching mangle described in CALENDERING, the trough containing the thickened colouring matter instead of starch. A roller covered with blanket dips partly into the trough, and above and in contact with this is another roller, and the cloth to be padded passes between the two. When the cloth is uniformly imbued with the colour, it is dried at a temperature of 212°. If the colour is to be applied to the face of the cloth only, the common printing machine with a roughened roller is used instead of the padding machine. The ground is sometimes produced by the union of two colours in solution forming within the fibre of the cloth itself an insoluble coloured precipitate. For this purpose the cloth is first passed through one coloured solution, and then dried. It is next passed through the other coloured solution; the two then react upon each other, and produce the desired effect. Or the cloth may be padded in one solution, and afterwards winced in the other. In order to produce a design on a white or coloured ground, the cloth is printed with one of the solutions, and then padded or winced in the other.

In the next style of printing, the *resist style*, the white cloth is printed with a *resist paste*, the object of which is to prevent those portions of the cloth to which it is applied in the form of a pattern, from taking up colour when the cloth is passed through the dye-beck. A white design on a coloured ground is a simple example of this style. There are two classes of resists, one to prevent a mordant from attaching itself to the portions of the cloth so protected, and the other to shield the cloth from colouring matter. Some resists act mechanically; such are *fat* resists. Others act chemically as well as mechanically.

The object of the fifth or *discharge style* is to produce a white or coloured figure upon a coloured ground. For this purpose the dyed or mordanted cloth is printed with a substance called the *discharger*, which acts either on the colouring matter or on the mordant before the cloth is exposed to the dye. The discharger acts by converting the colouring matter on the mordant into colourless or soluble products, which may thus be removed so as to allow the parts thus discharged to be dyed in another colour. A vegetable or animal colouring matter is usually discharged by chlorine and chromic acid; and a mordant is dissolved by an acid solution.

By this style are produced the well-known imitations of Bandana handkerchiefs, in which white figures are formed on a ground of Turkey-red by means of an aqueous solution of chlorine. This is made to flow down through the red cloth in certain points, which are defined and circumscribed by the pressure of hollow lead types inserted into plates of lead contained in a hydraulic press. The press is furnished with a pair of pattern plates, one attached to the upper block of the press, and the other to the movable part or sill. From twelve to fourteen pieces of cloth previously dyed in Turkey-red are stretched over each other as evenly as possible, and then rolled round a drum. A portion of the fourteen layers equal to the area of the plates being drawn through between them, the press is worked, and the plates are brought together with a force of upwards of 300 tons. The solution of chlorine is then allowed to flow into the hollows of the upper lead plate, whence it descends on the cloth, and percolates through it, extracting the Turkey-red dye, the intense pressure preventing the bleaching liquor from spreading beyond the limits of the figures perforated in the plates. When a certain quantity of bleaching liquor has passed through, water is admitted in a similar manner to wash away the chlorine. The pressure is then removed, and another square of the fourteen layers is moved forward under the plates, and the process is repeated. When all the pieces have been discharged, they are winced in water, and further treated so as to improve the lustre both of the white and of the red.

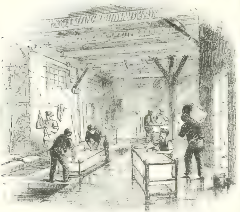


Fig. 417.—Indigo Vats.

The sixth and last style of printing is for *china-blue*, a peculiar style, practised with indigo only, two or three shades of colour being commonly associated with white. The bleached calico is printed of the required pattern with a mixture of indigo, orpiment, sulphate of iron, gum, and water. It is then aged for a day or two, and afterwards stretched in perpendicular folds on a rectangular frame of wood, Fig. 417. This is immersed in a certain order in three liquids, contained in stone cisterns, the tops of which are on a level with the ground: 1. in milk of lime; 2. in a solution of sulphate of iron; 3. in a solution of caustic soda. The frames are dipped several times alternately into the first and second cisterns, with exposure to the air for a short time between each dip: they are not dipped so frequently into the third cistern, but the dipping into this follows immediately after that in No. 2. By these operations, the insoluble indigo which had been applied to the surface becomes converted into soluble indigo, or *indigotin*, [see DYEING,] which is dissolved and transferred to the interior of the fibres, where it is precipitated in the original insoluble form.

Such is a general outline of the mechanical and chemical arrangements of a large print-work. In addition to these, every calico-printer must have the means of producing a constant succession of new patterns; for, were he to neglect to satisfy the craving after novelty in dress which seems to form a part of the mental constitution of all classes, his goods would be neglected, however fine in material, excellent in weaving, elegant in design, and tasteful in the choice, variety, and combination of colour. The spring or the winter fashions of each year must be *new;* and although millions of patterns have preceded those of any particular year, yet the patterns of each year must be stamped with the characteristic of novelty, or they will not sell. The production of this novelty requires months of previous preparation; and it is the business of a peculiar set of artists or pattern designers to furnish the printer with a large variety of designs, from which he selects those which he thinks likely to suit the taste of his customers. In some cases, the new patterns are sent out first to the distant foreign markets, such as those of South America: in other cases, patterns which have become old in this country are sent to the colonies, or to distant parts, as new; just as the fashionable novel, which has accomplished its short cycle of one season, is sent abroad, to initiate our colonists into the mysteries of high life at home.

A set of designers is usually attached to large print-works, consisting of two or three artists, and four or five apprentices. The designs furnished by them often amount to several thousands every year, from which the printer selects those which appear likely to succeed, either from novelty of design or the tasteful distribution of form and colour. Some designers work on their own account, and sell their designs at prices varying from a few shillings to many pounds. A skilful designer may meet with permanent employment at five or six guineas per week; but the average varies from 35*s*. to 50*s*. per week. Some printers have agents in the towns of France, and elsewhere, where print-works are carried on, and it is their duty to forward to their employers specimens of all the new patterns, as fast as they appear. The French are as superior to us in the art of design as we are to them in the mechanical departments of calico-printing. It is, however, to be hoped that the Schools of Design which have been established in the manufacturing towns of this country will do much to cultivate and improve the native taste. Whatever patronage is bestowed on these excellent institutions will, if properly applied and rightly directed, be a national benefit.

An Act passed in the 34th George III. gave to the inventor or printer of any new and original pattern for printing linen, calico, cotton, or muslin, the sole right and property in the same for three months from the time of publication. This was felt to be an insufficient protection; for no printer would employ an eminent artist to produce designs which in so short a time would become public property. Accordingly, a parliamentary inquiry was instituted, with a view to extend the copyright of designs, and in 1840 a select committee of the House of Commons published their report, which was favourable to such extension. In September, 1842, a new Act came into operation, by which a copyright of nine months was secured to designs for "garment-printing," and of three years to designs for "furniture-printing;" every design to be registered in a book kept by a registrar appointed by the Board of Trade. The greater protection granted to furniture-printing was on account of their being more costly than garment-prints; the mere drawing and engraving of some furniture-patterns costing from 50*l.* to 100*l.* A still greater expense is incurred in "making out the pattern:" that is, reducing it to such a scale, and making such a distribution of its parts, as will cause the several portions to "justify," or fit in with each other, when engraved on separate blocks or cylinders. Some patterns require to be drawn five or six times, because a very small imperfection in furniture-designs is at once detected. The patterns are designed on white card, each about 12 or 14 inches by 8 or 10, or less than this; the object being to give so much of the pattern as will represent it fairly. When a pattern has been approved, it is examined, to ascertain that every *repeat* is equidistant, that it is repeated at proper distances, and that there are not four sketches and a half, or five and a half, or five and a quarter, in what would be the circumference of the roller: a sketch is prepared which is made to agree exactly with the roller.

The reader who is interested in this subject will find a variety of curious and useful information in the minutes of the evidence taken before the Parliamentary Committee. The limits of this article will allow us to give only a few brief particulars. Mr. Salis Schwabe, a Manchester calico-printer, stated that the designing portion of his establishment cost about 800*l.* per annum. In 1838, between two and three thousand designs were produced, of which 500 were selected for engraving. The whole cost for designing and engraving these patterns was from 5,000*l.* to 5,500*l.*, or an average of 11*l.* per pattern; about 700 rollers being required to make out the 500 patterns. Of these patterns, 100 were decidedly successful, and 50 had a middling result. The cost of the unsuccessful patterns must of course be borne by the successful ones; thus bringing the cost of each successful pattern to about 35*l.* Two or three months are usually occupied in designing and engraving patterns, previous to their being ready for taking orders. Designs for light goods are got ready for the engraver in June, July, and August. In this last month the engravers have completed a portion of their work, and in September the first exhibition of patterns takes place, preparatory to sales for the distant markets, such as those of South America; but many of these patterns are suitable for the home market afterwards. Orders are taken for the home market in January, and the goods are delivered in February and March; so that the same designs may be published for one market in October, and for the home market in March. The sale continues throughout the summer.

When the printer has his own idea of a new pattern, he describes to the designer in words the style, the stripe, check, diagonal cut, natural flowers, or other objects. He does not exhibit another pattern, for, as Mr. Schuster remarked, "I have found by experience that indolence is an inherent quality even of draftsmen, and that they will come very near if I give them a pattern, and consequently I have desisted from that plan," for a pattern "assists the draftsman in remaining idle, in not exerting his own ingenuity in composing, in producing *novelty*," which is the thing most wanted.

One of the most novel and original patterns ever produced was by accident. Messrs. Simpson & Co. having to print a quantity of cloth in parallel stripes, as one piece was going up on the blanket the next piece came in another shape on the other side and cut a little across the pattern, so that the stripes being thrown angularly on each other, produced a new effect, which received the name of the *Diorama* pattern. This became so great a favourite that the printers are said to have sold 25,000 pieces of it in one day.

It appears from the evidence of several of the witnesses before the Committee, that the art of design has retrograded in England. When the printing trade was confined to the vicinity of London, pattern-drawing flourished. Mr. Thomson of Clitheroe says:—"The designs of several distinguished artists are still remembered with admiration; and Raymond, Kilburn, Wagner, and Edwards, are regarded as the old masters of the English school of design in calico-printing. I have the good fortune to possess a volume of drawings of this period, in which pattern drawing is elevated to the dignity of a fine art. The art of printing since that period has made gigantic strides, and is now one of the most beautiful and refined of the chemical arts. The art of designing has at the same time retrograded." Other witnesses stated that the best printers did not hesitate to copy French patterns almost exactly.

There are many excellent treatises on Calico-Printing. The most elaborate is that by M. Persoz, Professeur à la Faculté des Sciences de Strasbourg, entitled, "Traité théorique et pratique de l'Impression des Tissus," 4 vols. 8vo. Paris. 1846, with a quarto atlas of plates. The work itself contains 165 wood engravings and 429 actual specimens of printed calico in its various stages and styles, neatly pasted in among the type, producing a very pleasing effect. These specimens were furnished to the author by some of the principal calico-printers of Alsace, Switzerland, Normandy, the environs of Paris, England, and Scotland. Each house sent a sufficient quantity of print for the whole impression of the work, accompanied by a written description of the process adopted for producing each specimen. This highly useful method of illustration was first adopted in 1835, by Dr. Thomas Thomson, who published in the "Records of General Science," a valuable series of papers on this Art. It has also been adopted by Mr. Parnell in his Treatise on Calico-Printing, contained in his excellent work on "Chemistry applied to Manufactures," 8vo. London. 1843. [See Appendix.]

CALOMEL, the protochloride of mercury. See Mercury.

CALORIMETER, see Heat—Thermometer.

CAMBOGE or GAMBOGE, a gum resin, forming a well-known yellow water-colour. The best gamboge is from Siam and the kingdom of Camboja, (whence its name,) and is said to be the produce of *Garcinia Cochinchinensis*, the broken leaves and branchlets of which form a yellow milky juice, which is run into bamboos, so as to form cylindrical sticks. Another kind, which is suffered to harden in masses, which are covered with leaves, is said to be derived from *Cambogia gutta*. Dr. Wight, however, states that the tears of cambogia gutta are a substance altogether distinct from true gamboge. The best gamboge is brittle and inodorous, of conchoidal fracture, orange-coloured, or reddish yellow, smooth, and somewhat glistening. Its powder is bright yellow. It may be resolved into resin and gum by the successive action of ether and water. The finest gamboge contains about 70 per cent. of resin, sometimes termed *gambodic acid*, which forms numerous salts. Gamboge is used as a pigment, and in miniature-painting; also to tinge gold varnish. In medicine it is used as a drastic purge. It is sometimes improperly used by confectioners to colour liqueurs. An artificial gamboge, of very little value, is manufactured with turmeric and other materials.

CAMBRIC, a species of very fine white linen, first made at Cambray, in French Flanders, whence the name.

CAMEL, a machine invented in Holland, about 1688, for raising ships by the buoyant power of water. It consists of two similar hollow water-tight vessels, so constructed that they can be applied on each side of the hull of a ship. On the deck of each vessel windlasses are attached, which work the ropes passed under the keel of the vessel to be raised. When the camel is employed to raise a ship, the water is allowed to fill each half of it; and when the ship is firmly attached to the camel, the water is pumped out, and the buoyancy of the hollow vessels raises up the ship. A ship drawing 15 feet water could by this means be made to draw only 11 feet; and the largest man-of-war in the Dutch service could be made to pass the sand-banks of the Zuyder Zee. The length of one of these camels was 127 feet; the breadth at one end 22 feet, and the other 13 feet: the hollow part was divided into several compartments.

CAMLET, or CAMBLET, a plain stuff, of which there are several varieties. Some are made of goats'-hair; in others, the warp is of hair, and the woof half hair and half silk; others, again, are entirely of wool; and in some, the warp is of wool and the woof of thread. There are striped, watered and figured camlets.

CAMPHINE, see Turpentine.

CAMPHOR is the produce of the *Laurus camphora*, or *camphor laurel*, of Japan and China. The roots and wood of the tree are chopped up, and boiled with water in an iron vessel, to which an earthen head containing straw is adapted; and the camphor sublimes, and condenses upon the straw. In China, the chopped branches are boiled in water till the camphor begins to adhere to the stirrer: the liquor is then strained, and the camphor concretes on standing: it is afterwards mixed with a finely powdered earth, and sublimed from one metallic vessel into another. Two kinds of unrefined or crude camphor are known in commerce: 1. *Dutch* or *Japan camphor*, also called *tub-camphor*, from the circumstance of its being brought from Batavia (and reported to be the produce of Japan) in tubs, covered by matting, each surrounded by a second tub, secured on the outside by hoops of twisted cane. Each tub contains from 1 cwt. to 1¼ cwt., or more. It consists of pinkish grains, which by their mutual adhesion form lumps. It is of larger grain, clearer, and sublimes at a lower temperature than the second variety, which is known in commerce as *ordinary crude camphor*, *China camphor*, and *Formosa camphor*. This is imported from Singapore, Bombay, &c., in square chests, lined with lead foil, and containing from 1¼ to 1½ cwt. It is chiefly produced in the island of Formosa, and is conveyed in junks to Canton, whence the foreign markets are supplied. It consists of dirty greyish grains. It varies in quality, but is sometimes as fine as the Dutch kind.

Crude camphor very much resembles moist sugar before it is cleaned. It is refined, and converted into the beautiful well-known article sold in the shops, by sublimation. This process is carried on in spheroidal vessels, called *bomboloes* (Fig. 418). They are made of thin flint glass, and weigh about 1 lb. each, and measure about 12 inches across. Each vessel has a short neck. When filled with crude camphor, they are imbedded in a sand-bath, and heated to a temperature of from 250° to 280°, which is afterwards raised to between 300° and 400°. About 2 per cent. of quick-lime, and 2 parts bone-black, in fine powder, are added to the melted camphor, and the heat raised,

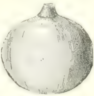


Fig. 418.

so as to boil the liquid. The vapour condenses in the upper part of the vessel. As the sublimation proceeds, the height of the sand around the vessel is diminished. The process is completed in about 18 hours. This operation requires considerable attention and experience. Dr. Ure says:—"If the temperature be raised too slowly, the neck of the bottle might be filled with camphor, before the heat had acquired the proper subliming pitch; and if too quickly, the whole contents might be exploded. If the operation be carried on languidly, and the heat of the upper part of the bottle be somewhat under the melting point of camphor, that is to say, a little under 350°, the condensed camphor would be snowy, and not sufficiently compact and transparent to be saleable. Occasionally, sudden alternations of temperature cause little jets to be thrown up out of the liquid camphor at the bottom upon the cake formed above, which soil it, and render its re-sublimation necessary."

The vessels being removed from the sand-bath, the mouth is closed with tow, and in this hot state, water is sprinkled over them, and they crack. When quite cold, the cake of camphor, weighing about 11 lbs., is removed, and trimmed, by paring and scraping into the form of large hemispherical cakes, perforated in the middle. In this process the lime retains the impurities and a portion of the camphor: the latter is recovered by heating the mixture in an iron pot, with a head to it, and the product is refined by a second sublimation.

In a large chemical factory near Birmingham, which the Editor was allowed to visit, the camphor-refining room contained about a dozen sand-baths, standing parallel to each other across the room, each containing about ten bombolos. The temperature of the room was about 150°, very dry, and highly charged with vapour of camphor. This being inflammable, means are taken to obtain heat and light without the introduction of fire into the room. Accordingly, the sand-baths are heated from baths of fusible metal, kept at the proper temperature by a furnace outside; and, to diminish the escape of the camphor vapour, each bombolo was covered with a glass shade. Another use of this shade was stated to be, to exclude the air, which, if admitted, would cause the sublimed camphor to be opaque instead of clear. It was also stated that the essential oil is driven off from the crude camphor, before subliming. [See APPENDIX.]

Camphor ($C_{20} H_{16} O_2$) is a white and semi-transparent solid (sp. gr. 0·996), of a crystalline fracture, a peculiarly fragrant odour, and a warm, pungent, and somewhat bitterish taste, accompanied by a sense of coldness on the tongue. It is soft and tough, but can be readily pulverised if moistened with a few drops of spirits of wine. It evaporates in the air at ordinary temperatures, and gradually sublimes in close vessels, and attaches itself to the surfaces most exposed to the light. If a vessel exhausted of air, and containing a piece of camphor, be exposed to the direct rays of the sun, these crystals will be formed speedily. When small pieces of perfectly clean camphor are allowed to fall upon the surface of pure water, they rotate and move about with great rapidity, sometimes for several hours together; but if, while the camphor is rotating, the surface of the water be touched with any greasy substance, (a glass rod dipped in turpentine answers best,) all the floating particles quickly dart back, and are instantly deprived of all motion.[1] The motions of the camphor are accelerated by placing the glass in vacuo. Camphor fuses at 347°, and boils at 399°, when it may be distilled without decomposition. The density of camphor-vapour is 5.31. Camphor is sparingly soluble in water; 1 part of camphor requiring about 1,000 parts of water for solution. This aqueous solution is named *camphor julep.* It is very soluble in alcohol, ether, acetic acid, sulphuret of carbon, and some other substances. 100 parts of spirits of wine (specific gravity 0.806) dissolve 120 of camphor, forming the *camphorated spirit* of the Pharmacopœia. On adding water to this, nearly all the camphor is thrown down, in a minutely divided state. Considerable use is made of camphor in medicine, both as an internal and an external remedy; but it ought never to be taken internally without medical advice. A dose of two scruples appears to be sufficient to cause death.

Camphoric acid ($2 HO, C_{20} H_{14} O_6$) is obtained by the action of nitric acid upon camphor.

CAMWOOD, a red dye-wood, obtained from the vicinity of Sierra Leone. Its colouring matter differs but little from that of Nicaragua wood.

CANAL, see NAVIGATION, INLAND.

CANDLE, a cylinder or slightly conical rod formed of solid fat, in the axis of which a bundle of parallel, twisted or woven fibres is enclosed.

It is necessary to the due comprehension of some of the details of candle-making to enter briefly into the chemistry of fats and oils, substances of first-rate importance to the welfare of a country, the large proportion of carbon contained in them rendering them valuable sources of food and artificial light. Most fats and fixed oils, vegetable and animal, are mixtures of two, and generally three distinct compounds, each of which taken singly has all the properties of fats. The first of these substances, called *stearine,* (from *στέαρ*, tallow or suet,) is solid at common temperatures; it constitutes the solid fatty ingredient in mutton-tallow; the second is *oleine,* (from *ἔλαιον, oleum,* oil,) and is liquid at ordinary temperatures, and down to the temperature of freezing water; the third substance is named *margarine,* (from *μάργαρον*, a pearl,) on account of its mother-of-pearl lustre: it is solid at ordinary temperatures. All fats may therefore be regarded as mixtures of the fluid oleine with the solid stearine or margarine. If the solid be in larger proportion than the fluid, as in various kinds of tallow, it requires a greater degree of heat to melt it. If the fluid portion prevails, as in the oils, the melting point is lowered.

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(1) Raspings of cork, steeped in sulphuric ether, sublimated benzoic acid, thin slices of crystallized citric acid, the butyrates of potash, baryta, lime and magnesia, potassium, and some other substances, also rotate and move about on the surface of water. The amalgams of potassium, or of sodium and antimony, bismuth, lead, &c., rotate on the surface of mercury.

Each of these three substances contains an organic base, or substance capable of uniting with acids to form (in most cases) a neutral compound. This base is named *glycerine* or *hydrated oxide of glyceryl*,[1] and is united with an unctuous substance which has acid properties. The glycerine is common to all the three fatty principles, but the acid in each has its own peculiar characters. Thus, the acid in *oleine* is termed *oleic acid*, which combining with the oxide of glyceryl of the oleine, forms *oleate of glycerine*. So also the acid of *stearine* is called *stearic acid*, which in combination with the oxide of glyceryl of the stearine forms *stearate of glycerine*. Again, the acid of *margarine* is called *margaric acid*; this combining with the oxide of glyceryl of the margarine forms *margarate of glycerine*. [See OILS and FATS.]

All these fatty compounds are decomposed by free alkalies, such as potash and soda; their acids quitting the glycerine to unite with the alkalies, forming a soluble soap, while the glycerine is left behind in the mother liquor. The hard soaps of commerce when made with oils (palm and cocoa-nut oils excepted) are chiefly mixtures of oleate and margarate of soda, with little if any stearate. When the hard soaps are made with animal fats, they are mixtures of oleate, stearate and margarate of soda. [See SOAP.]

The chief material used in making candles is tallow. This substance is the concrete fat of oxen, deer, sheep, and other large quadrupeds, separated from the fibrous matter which accompanies it. There are two principal varieties of tallow, arranged according to their purity and consistence into *candle* and *soap tallow*. It is generally sufficiently pure for soap-making without previous preparation. The supply is made up by home slaughter, and also by importation, chiefly from Russia, which supplies us every year with no less a quantity than 60,000 or 70,000 tons. A large quantity is also sent from Australia and from the states of Rio de la Plata. The importation of tallow is still on the increase.

Candles are also made in very great numbers from palm oil. This substance is obtained from the western coast of Africa, south of Fernando Po, from the fruit of the oil palm (*Elais guineensis*). The fruit externally is of a golden yellow colour, and about the size and shape of a pigeon's egg. Its fleshy covering is detached from the kernel and bruised into a paste, which being agitated with boiling water, the oil rises to the surface and concretes as it cools. Fresh palm oil is of an orange yellow colour, of a sweetish taste, and of an odour resembling that of violets. Its melting point is 81°, but after the oil has been kept some time it melts at 90° or 96°. The oil becomes rancid by exposure to the air, and glycerine and fatty acids are liberated. It contains about two-thirds of its weight of a peculiar white solid fat, which has been named *palmitine*, the remainder consisting chiefly of oleine. Upwards of 25,000 tons of palm oil are annually imported into this country in exchange for goods of British manufacture. This trade, profitable alike to Africa and to Great Britain, has also a favourable effect in checking the slave trade, the services of the natives at home being required for preparing the oil.

Such are the chief materials used in the manufacture of candles. Ordinary candles are made of tallow, and are either *dipped* or *moulded*. Mutton suet with a proportion of ox-tallow is used for mould candles, which are required to be hard, and to have a glossy surface. Course tallow is used for *dips*. The first operation in candle-making is to sort and melt the tallow, and this should be done as soon as possible after the fat has been removed from the carcass, because the fibrous and fleshy substances mixed with it promote putrefaction. The tallow is usually melted in an open copper exposed to the direct action of the fire, and after fusing for a considerable time, the membranous matters collect at the surface. These are removed, and after the fat has been squeezed out at a press, they form *greaves* or *cracklings*, sometimes used for feeding dogs. The melted tallow is passed through a sieve into another copper, where it is washed with a quantity of boiling water. The impurities settle down with the water at the bottom of the copper, and the purified tallow is lifted out in buckets of tinned iron into tubs, where it cools and is ready for use.

In the method adopted in France and on the Continent for extracting the fatty matters from the cells or tissues in which they are confined, the direct action of fire is not employed, but the simple agency of steam combined with dilute sulphuric acid. The fatty matter is left to macerate for a day or two with very weak oil of vitriol, after which about 400 lbs. are taken out of the macerating tubs, and put with 24 gallons of water and 7 lbs. of sulphuric acid (specific gravity 1.845) into proper wooden vessels, where the mixture is subjected to a jet of steam, which soon causes the whole to boil. Under the influence of heat and of the weak vitriol, the nitrogenized tissue which envelopes the grease is rapidly destroyed, and the liberated fatty matter floats on the surface of the boiling water perfectly free from all foreign matters; after which the jet of steam is stopped, and the tallow is let off by a tap into a proper receiver. The simple addition of a little vitriol reprepares the melting vessels to receive a new charge of macerated fat, which also becomes fit for letting off after a short time.

Larger pans are required than those used in England to do the same amount of work; but the operations are performed more quickly. From 100 lbs. of fatty matter 85 lbs. of tallow are produced by this method, whilst the more dangerous one now practised gives only 82 lbs., so that the manufacturer gets three per cent. more tallow by the above process, which amply repays him for the 5½ lbs. of scraps which are in a great measure lost. But the animal matters remaining in the pan can be used as manure, or, by mixing them with saw-dust, as fuel. This method renders tallow-melting safe, and gets rid of

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(1) The oxide of glyceryl, at the moment of its liberation, unites with water. This acid has not been insulated. If it were so, it would bear the same relation to glycerine as ether does to alcohol.

that most disagreeable odour which characterises the neighbourhood of tallow-melting establishments.

The wicks used for the best candles are cotton rovings imported from Turkey. Four or more skeins, according to the thickness of the wick, are wound off at one time into bottoms or clues, and afterwards cut to the proper lengths, being first doubled and twisted so as to leave a loop at one end. Wicks for dip candles are also cut very expeditiously by machinery. Balls of cotton previously made into a loose roving or cord, consisting of a dozen or more threads each, and differing in thickness according to the size of the candles, are put into a box or drawer. The ends are then attached to a rod or broach, and equal lengths of cotton are cut off by drawing a knife along a whole range of them at once, a slight twist being given to the whole of them by the action of the machine. When the wicks are cut to the proper length they are dipped into melted tallow and rubbed between the palms of the hands; and on being left to harden they are arranged upon smooth sticks or broaches about half an inch in diameter and three feet long, for the purpose of dipping. The dipping-room contains a boiler for melting the tallow, a dipping-mould or cistern, and a large wheel for supporting the broaches. A long balance-shaped beam is suspended from the ceiling, to one end of which is attached a wooden frame for holding the broaches with the wicks properly arranged. The opposite end of the beam has a scale-pan with weights to counterbalance the wooden frame, and to enable the workman to determine the size of the candles. The end of the lever which supports the frame is situated just above the dipping-cistern, so that by gently pressing down the balanced beam, the wicks descend into the melted tallow, Fig. 419, which is kept in a proper state of fluidity by a brazier or a bath of hot water on the outside. The wicks are dipped three times for the first *lay*, and after being kept a short time over the cistern for the wicks to drain, the sticks are placed on a rack, and the candles are left to harden. The same process is repeated a second and third time, or oftener, according to the required weight of the candles, a sufficient time being allowed between each dipping for the tallow to consolidate; hence the dipping-room requires to be kept cool; for which purpose the business of candle-making is confined to the cooler months of the year; but if carried on in summer, the cooler part of the night is the time preferred.

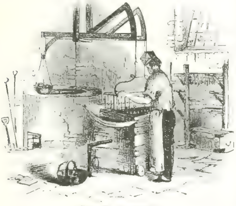
FIG. 419. DIPPING.

Various machines for dipping candles have been introduced. They do not require any special description, but we may refer to one that has been long in use at Edinburgh. It consists essentially of a strong upright post, turning upon pivots, and supporting a wheel with 12 horizontal arms, from the end of each of which is a frame or *post* containing 6 rods, on each of which are 18 wicks, making altogether 1,296 wicks. On turning the wheel round, each post is brought in succession over the dipping-mould, and the wicks receive a fresh coating. The constant motion through the air tends to consolidate the tallow, and it is stated that in moderately cold weather, a wheel of common-sized candles can be finished in two hours.

The moulds used in making mould candles are of pewter, and consist of two parts; namely, a hollow cylinder of the length of the candle open at both ends, and nicely polished on the inside; and a small metallic conical cap with a hole in the centre for the wick. Glass moulds have also been lately introduced. 8 or 12 of these moulds are fixed in a wooden frame, the upper part of which is a trough, into which the open extremities of the moulds are inserted on a level with its surface, so that the tops of the moulds point downwards. In order to insert the wicks the frame is placed on its side, and the man introduces a hooked wire into the mould, and passing it out through the point at the top attaches to it the loop of a wick, a number of which he holds in his left hand; he then draws back the wire, and brings the wick along with it. All the moulds being thus provided, another man passes a small wire through the loop of each wick, for the purpose of keeping it stretched in the centre, or along the axis of the cylinder. The moulds are filled by running tallow into the trough from a boiler kept at the proper temperature, and furnished with a cock or tap. When the moulds are almost half filled the supply of tallow is cut off, and the workman laying hold of the portion of each wick that projects from the point pulls it tight. This prevents the wick from curling, and secures it in its proper position. The filling is then completed, and the frame put aside to cool. The candles ought to remain in the moulds until the next day, but it is known when they are properly set by a snapping noise produced by pressing the thumb against the bottom of the moulds. When this occurs the wires are pulled out, the superfluous tallow is scraped off with a small wooden spade; a bodkin is introduced into the loop of the wicks, and the candles are withdrawn in succession. They are then removed to the storehouse, where in the course of a few months they become sufficiently white for sale. No duty is now paid on candles.

The tallow used in moulding is sometimes melted over a solution of alum, the sulphuric acid of which appears to act as a purifier. The proper consistence for moulding is judged of by the appearance of a scum on the surface, which forms in hot weather between 111° and 119° Fahr.; in mild weather at 108°, and in cold at about 104°.

Wax is not adapted for moulding, in consequence of the contraction which it undergoes in cooling, and the tenacity with which it adheres to the sides of the moulds. Wax candles are made in the following manner:—A set of wicks properly cut and twisted, and warmed at a stove, are attached to a ring of wood or metal, and suspended over a basin of melted wax, which is taken up by a large ladle and poured on the tops of the wicks, each wick being kept constantly twisted round its axis by the fingers; the wax in running down adheres to the wicks, and completely covers them. This process is repeated at intervals until a sufficient thickness is attained. The candles are then rolled while hot with a flat surface of box-wood upon a smooth table of walnut-wood kept constantly wet; this makes them truly cylindrical. This basting, twisting of the wicks and rolling is sometimes repeated two or three times before the candles are finished, but a skilful workman will cover the wicks with the proper quantity of wax without taking them down. If a wax candle be broken across, the annular layers, like the yearly rings in wood, can be easily counted, and their number indicates the number of times the wax has been poured over the wick.

The large wax candles used in Roman Catholic churches are made by placing a wick upon a slab of wax, bending this together and then rolling it.

The long, thin, coiled wax tapers are made in the following manner:—the wick, which must be uniform, is wound round a drum, from which it is passed into the wax pan, at the bottom of which is fixed a guiding roller, and from thence through a drawing plate to a second drum. The drawing plate is of metal, and is similar to that used in wire-drawing: the holes in it correspond in size to the diameter of the taper, and the wick is passed through smaller and smaller holes until it is of the proper thickness.

Rush-lights are made in the same manner as dip candles. The Rev. Gilbert White, in his "Natural History of Selborne," describes the method of making them by the cottagers of Hampshire. He says:—"The proper species of rush for this purpose seems to be the *juncus effusus*, or common soft rush, which is to be found in most moist pastures, by the sides of streams and under hedges. These rushes are in best condition in the height of summer; but may be gathered, so as to serve the purpose well, quite on to autumn. It would be needless to add, that the largest and longest are best. Decayed labourers, women, and children, make it their business to procure and prepare them. As soon as they are cut they must be flung into water, and kept there; for otherwise they will dry and shrink, and the peel will not run. At first a person would find it no easy matter to divest a rush of its peel or rind, so as to leave one regular, narrow, even rib from top to bottom that may support the pith: but this, like other feats, soon becomes familiar even to children; and we have seen an old woman, stone blind, performing this business with great despatch, and seldom failing to strip them with the nicest regularity. When these *junci* are thus far prepared, they must lie out on the grass to be bleached and take the dew for some nights, and afterwards be dried in the sun.

"Some address is required in dipping these rushes in the scalding fat or grease; but this knack also is to be attained by practice. The careful wife of an industrious Hampshire labourer obtains all her fat for nothing; for she saves the scummings of her bacon-pot for this use: and if the grease abounds with salt, she causes the salt to precipitate to the bottom, by setting the scummings in a warm oven. Where hogs are not much in use, and especially by the sea-side, the coarser animal oils will come very cheap. A pound of common grease may be procured for four-pence; and about 6lbs. of grease will dip a pound of rushes; and one pound of rushes may be bought for one shilling; so that a pound of rushes, medicated and ready for use, will cost three shillings. If men that keep bees will mix a little wax with the grease, it will give it a consistency and render it more cleanly, and make the rushes burn longer: mutton suet would have the same effect. A good rush, which measured in length 2 feet $4\frac{1}{2}$ inches, being minuted, burnt only 3 minutes short of an hour. These rushes give a good clear light. Watch lights (coated with tallow) it is true shed a dismal one, 'darkness visible;' but then the wicks of those have two ribs of the rind or peel to support the pith, while the wick of the dipped rush has but one. The two ribs are intended to impede the progress of the flame and make the candle last.

"In a pound of dry rushes, avoirdupois, which I caused to be weighed and numbered, we found upwards of 1,600 individuals. Now suppose each of these burns, one with another, only half an hour, then a poor man will purchase 800 hours of light, a time exceeding 33 entire days, for three shillings. According to this account, each rush before dipping costs $\frac{1}{33}$d of a farthing, and $\frac{1}{11}$th afterwards. Thus a poor family will enjoy $5\frac{1}{2}$ hours of comfortable light for a farthing. An experienced old housekeeper assures me that $1\frac{1}{2}$lb. of rushes completely supplies his family the year round, since working people burn no candle in the long days, because they rise and go to bed by day-light. Little farmers use rushes much in the short days, both morning and evening, in the dairy and kitchen; but the very poor, who are always the worst economists, and therefore must continue very poor, buy a halfpenny candle every evening, which in their blowing open rooms does not burn much more than 2 hours. Thus have they only 2 hours' light for their money, instead of 11." [1]

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(1) It will be remembered that these observations were written in the year 1775. Since that time tallow has become much cheaper, and the trade of candle making has risen to the dignity of a manufacture, which, together with the repeal of the duty on candles, has had the effect of considerably lowering the price

Considerable improvements have been made of late years in the manufacture of candles, by decomposing the fatty or oily substances used for the purpose, and employing the stearine (stearic acid) or palmitine (palmitic acid) only. We will first describe the processes adopted in the manufacture of stearine candles, taking as our chief authority, the account given by M. Dumas in the sixth volume of his "Traité de Chimie appliquée aux Arts." (1843.)

If the reader will again refer to the constitution of fatty substances as stated at the commencement of this article, the following details will be intelligible. [See also OILS and FATS.]

The first process consists in destroying the combination of the fatty acids with the glycerine by means of lime which displaces it, whereby stearate, margarate, and oleate of lime, are produced in the form of a solid soap, and the glycerine set at liberty is dissolved in the water necessary to determine the combination. The lime must be as caustic as possible, and be thoroughly incorporated with the fat. For this purpose, about 1,100lbs. of fat are placed in a vessel of wood, slightly conical and of the capacity of about 100 gallons, together with a quantity of water sufficient to dissolve the glycerine: this will be about 50 gallons. The temperature of the whole is raised by introducing a jet of steam into the vessel, and when the fat is melted, about 150lbs. of lime well mixed up with water are added, and the whole well stirred up by machinery until the chemical changes shall have been effectually produced. Figs. 420, 421, show the arrangements of this vessel in section and plan. A central axle, which is connected at *a* with the moving power of the establishment, carries a number of horizontal arms, *b b*, furnished with teeth or cutters, shown on a larger scale above. The brisk motion of this stirrer causes the lime to combine with the fatty acids in a shorter time and with a less quantity of lime, than could be effected by stirring by hand labour. At the end of 6 or 8 hours, the saponification is complete; the liquid portion containing the glycerine in solution is drawn off, and the stearate, margarate, and oleate of lime, are then removed in the form of very hard soaps.

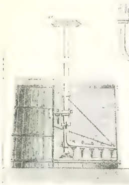


Fig. 420.

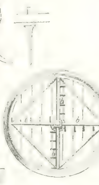
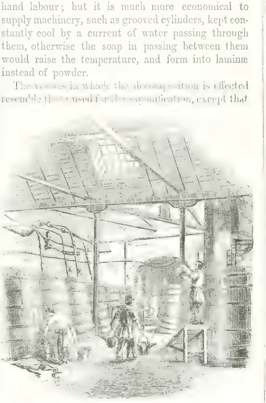


Fig. 421.

The next process is to separate the lime from the fatty acids: this is effected by means of dilute sulphuric acid, for which purpose, the weak acid as it leaves the sulphuric acid chambers, answers very well; hence the manufacturers of stearine find an advantage in having their works in close proximity to sulphuric acid works, or even in manufacturing the acid themselves, as the expensive process of concentration can be entirely dispensed with. [See SULPHURIC ACID.]

In order that the acid may act effectually upon the soaps, it is necessary that they should be reduced to powder. In some works this is done roughly by hand labour; but it is much more economical to supply machinery, such as grooved cylinders, kept constantly cool by a current of water passing through them, otherwise the soap in passing between them would raise the temperature, and form into laminæ instead of powder.

The vessels in which the decomposition is effected resemble those used for the saponification, except that they are lined with lead to preserve the wood from the action of the sulphuric acid. They are heated by a jet of steam or by a coil, and are furnished with an agitator. An excess of sulphuric acid is used to ensure the complete saturation of the lime, which forms a solid sulphate of lime, and sets the three fatty acids at liberty. The decomposition is effected in about 3 hours. The mixture being then left quiet, the fatty acids float on the surface, and the sulphate of lime falls to the bottom of the vessel. The fatty acids are drawn off by means of a stop-cock at the side, into a wooden vessel lined with lead, and heated by means of steam. The last traces of the lime are removed by washing with a very dilute solution of sulphuric acid. The fatty acids are next washed in another vessel with pure water, and are then drawn off into moulds of sheet-iron, the sides of which slope in towards the bottom, in order that they may deliver the cake of solid acid more readily.



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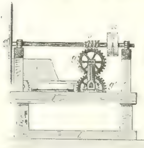
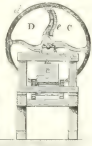
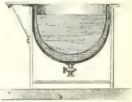
When the moulds have become cold, the cakes, weighing about 60 lbs. each, have a yellow tint and a greasy appearance, both which defects arise from the mechanical mixture of the liquid oleic acid, with the crystals of the solid stearic and margaric acids. The fluid acid is got rid of by subjecting the mass to strong pressure. For this purpose the cakes are cut up into slices by means of the machine shown in Figs. 423, 424. A knife *e* is let into one of the radii of a fly wheel, which is mounted on a horizontal axis, and moved by a strap passing over a fast and loose pulley, *k*. The motion of this axis also sets in motion an endless band *i*, on which the solid cake is placed, and by this means is brought up to the knife to be cut. It will be seen that the endless screw *f* on the axis of the fly gives motion to the toothed wheel *g*, and this in its turn to *g'*, which carries on its axis one of the rollers on which the endless band is made to move. These toothed wheels are so arranged that for every turn of the fly *d*, and consequently of the endless screw *f*, the cake *c* advances through a space equal to that of one of the slices cut off; and it is evident that whatever be the rate of motion of the fly, the slices will always be of the same thickness. The endless band is supported by a fixed plank to prevent it from being warped by the weight of the cakes.





As soon as the cakes are cut up, the slices are arranged in thin layers in bags of serge or on mats piled one above another. These are arranged on the stage of a hydrostatic press, and subjected to great pressure. A large portion of the oleic acid escapes with pressure only, but for the remaining portion, as well as for the margaric acid, the pressure must be assisted by heat. For this purpose the bags or mats are placed between strong, hollow, shallow boxes covered with felt, and filled with steam by means of jointed pipes, which admit of being lengthened or shortened without interfering with the supply of steam. The oleic acid is received into a vessel, where it deposits a quantity of stearic acid, which the high temperature has assisted in bringing over. This fluid acid is used in soap-making, and as a cheap oil for variegated lamps, and other purposes. The solid stearic and margaric acids are pressed a second time, after which they appear of a brilliant whiteness, and form more than 45 per cent. of the fat employed. They are then taken to vats, where they are further purified with very dilute sulphuric acid, which removes all remaining traces of lime and other impurities; and lastly, the sulphuric acid is removed by repeatedly washing with water. The vats in which these operations are conducted are all heated by means of steam, or have steam-jackets as in Fig. 425. After reposing for a time, the fatty acids are decanted into a lower vat containing pure water, which is frequently renewed. They are again left to repose, and are finally drawn off into moulds, in which the cakes are formed of a perfectly white colour, and fit for the manufacture of candles.



Palm oil, as already stated, is extensively used in the manufacture of candles. In order to obtain the beautiful white acids of which candles are now made, several plans have been adopted, of which the following is an outline. The oil, which is of an orange yellow colour, is bleached by exposure to the air in large shallow backs, or vessels similar to brewers' coolers. Water to the depth of 7 or 8 inches is first let into the backs, and this is raised to about the temperature of boiling water by means of coils of pipes filled with steam. The oil is then added, which soon melts and diffuses itself in an equable layer over the surface of the hot water. This layer ought not to be more than 1½ or 2 inches thick. By the united action of air, light, and a high temperature, the bleaching proceeds rapidly, and is completed in about 10 or 15 hours. The oil still has a slight reddish tint, and when cold is of a dirty white colour. In this state it is well adapted to the manufacture of an excellent white soap of great hardness. For the manufacture of candles it is put into woollen bags, and subjected to strong compression in a hydrostatic press, first at a temperature of about 55°, and a second time at the temperature of about 86°. The solid matter which remains is melted in a vessel containing a coil of pipe heated by steam. After resting for a time it is decanted, and 6 per cent. of wax is added. It is then fit to be employed in the manufacture of mould candles.

Davidson's method of bleaching palm oil consists in first melting it in an iron vessel lined with lead, with the addition of from 6 to 11 per cent. of chloride of lime previously mixed with 12 parts water. The ingredients are thoroughly incorporated, and left to become cold. The cakes thus formed are cut up into small pieces, and exposed to the air for two or three weeks. The chlorine which is liberated slowly bleaches the oil. The lime is then separated by dilute sulphuric acid, which disengages the remainder of the chlorine, and completes the bleaching. The objection to this process is, that the chlorine at a high temperature attacks the oil, decomposes the palmitic acid, and itself takes the place of the hydrogen of the acid.

Palm oil has also been bleached by the use of oxygen. The oil is mixed with $\frac{1}{16}$th of finely powdered manganese; boiling water equal to half the weight of the mixture is then added, and with constant agitation strong sulphuric acid equal to $\frac{1}{32}$d of the weight of the oil is poured upon the mixture. The mass is then allowed to cool. The solidified fat is of a greenish hue, but soon becomes white by exposure to air and light.

Palm oil poured slowly over a heated iron plate absorbs oxygen from the air with the evolution of an acid vapour, and becomes converted into a clear colourless fat. The colouring matter begins to decompose at the temperature of 230°, and when this heat has been attained over an open fire, the temperature is maintained by the introduction of a current of high-pressure steam, and the decomposition is promoted by constant stirring. 4 tons of palm oil can thus be decolorized in 10 hours.

The most complete and rapid, but also the most expensive method of bleaching, is by the use of bichromate of potash, and strong mineral acids. This is Watt's method, and consists in an oxidation of the colouring matter by chromic acid. The oil is first melted, and allowed to stand to deposit its mechanical impurities. The clear oil is then drawn off into wooden vessels, mixed with a concentrated solution of 25 lbs. of bichromate of potash, 8 lbs. of sulphuric acid, and about 50 lbs. of strong muriatic acid to the ton of oil. The whole is well stirred together. (Instead of muriatic acid, common salt with an additional quantity of sulphuric acid may be used.) In a few minutes the light green appearance of the oil, and the rising of a thick scum to the surface, indicate the completion of the process. It can readily be seen by the colour of specimens allowed to cool, whether a sufficient quantity of the bleaching material has been used. In this process, the sulphuric acid combines with the potash, and liberates the chromic acid, which parting with half its oxygen to destroy the colouring matter becomes converted into oxide of chromium. The muriatic acid forms a soluble compound with this green oxide, chloride of chromium. The bleached oil has now to be separated from the aqueous solution of chloride of chromium, (and of sulphate of soda when common salt has been used.) This separates as the heavier liquid upon which the oil floats when the warm mixture is allowed to repose during half an hour. The fat collected from the surface is then washed in a second vessel with water made to boil by a current of steam. The process of bleaching 1 ton of oil does not occupy more than 5 minutes, and the cost is about 16*s.* 6*d.* per ton.

The most extensive factory in this country of candles made from the bleached solid fat of palm oil is that of Price's patent candle Company at Belmont, Vauxhall. From a statement published in the Illustrated London News, and also from information furnished to the Editor during his visits to the factory, we learn that this Company working day and night employs above 700 hands, in addition to steam and hydraulic power, and consumes upwards of 4,000 tons of palm and cocoa-nut oil per annum. There are also branch works at Battersea. The oil is imported in large casks or tuns, and on arriving at the works, a steam-pipe is introduced into each, which has the effect of rendering the contents fluid. The oil thus liquefied is of a bright orange colour, and is conveyed through a pipe to reservoirs, where it is subjected to a chemical treatment similar to that already described for extracting stearine from animal fat. A part only of this process is conducted at Vauxhall; the remainder is performed at Battersea. The transit of the raw material (so to speak) between the two factories is managed by means of barges. When the material is returned to Vauxhall it is in the form of large cakes or lumps, which are cut into slices by means of a revolving cutter as before explained, Fig. 423. The solid cake is brought up to the cutter by means of an endless band, and the slices as they are cut off fall down a tube arranged like the tube of a telescope, so as to be shortened or lengthened at pleasure. At the bottom of this tube is a carriage provided with two heavy rollers, moving backwards and forwards through a space equal to that which two of the cocoa-fibre mats on which the fatty acids are spread would occupy when placed side by side. A mat is placed so as to occupy one half of the solid table on which the carriage moves; the first action of the rollers is to bring down a balanced iron frame upon the margins of the mat; the fat is then, by the action of the rollers, spread equally over the mat within the frame. The carriage then passes to the other half of the table, where a mat is covered in the same manner, and in clearing the first mat the balanced frame rises up and releases the covered mat, which is removed by an attendant, and a new mat is thrown down in its place. By the time the second mat is covered, and the place of the first mat occupied by the third, the carriage is moving towards the third, and releasing the second. In this way the mats are

Fig. [illegible]

quickly and equably covered, the space of an inch being left along each of the four edges of the mat in order that when these mats are piled up in the hydraulic press, the intense pressure may not force the

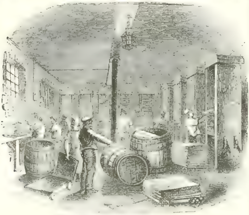


Fig. 427. HYDRAULIC PRESS-ROOM.

fatty matter out over the edges. These mats are piled up on trucks, and conveyed to the pressing department, Fig. 427, which contains 42 powerful hydraulic presses, the pumps of which are worked by steam power. When placed in the press an iron plate is introduced between each pair of mats for the purpose of giving greater stability to the pile. In the first pressure as much oleic acid is removed as can be got out at the ordinary temperature. The second pressure takes place at the temperature of 120°. The mats are then taken to the stripping bench, Fig. 426, where the cake, now reduced to a dry, solid, white substance, moulded to the surface of the mat by the intense pressure, is stripped off by hand. It is not, however, sufficiently white and pure for the purpose of candle-making. In the course of pressing and pulling about it has contracted iron-moulds and other impurities. It is therefore conveyed to the vats, Fig. 422, where it is washed in a hot solution of very dilute sulphuric acid.

After this, the fatty acids are conveyed to the candle-moulding department, the arrangements of which are on a very extensive scale. A long apartment, well lighted and ventilated, is occupied by double lines of railway, upon which the moulding-frames are moved. Beginning at the end of one of these lines of railway, we have both the commencement and the end of moulding a set of candles. Each moulding-frame is furnished with a tin box, containing 18 reels, and upon every reel is wound 60 yards of plaited cotton wick. The ends of these wicks are passed through eyes at the top of the moulds, and are held above the upper part of the moulding-frame by a set of forceps. By a very beautiful contrivance, the mechanism which expels the candles from one set of moulds draws in the cottons ready for the next filling. In Fig. 428 the workman at the end of the railway is in the act of separating the candles and rewicking the moulds. This being done, a lateral motion is given to the frame, whereby it falls from the horizontal into a vertical position, with the trough upwards, ready for filling, and is transferred from the left to the right-hand line of rails. A boy pushes the frame forward, and this in its turn is pushed forward by other frames succeeding, until it arrives at a hot closet, where it attains the temperature necessary for filling. If the moulds are filled at the ordinary temperature of the air, the fluid fat forms into large irregular crystals, giving the surface of the candle an unpleasant speckled appearance. It was found that by the addition of a small portion of arsenic, the crystals became more broken up, and the fat solidified in a homogeneous manner; but the use of arsenic being so very objectionable, and evident to the senses by the smell of garlic, whenever a candle was blown out, candles containing that poisonous compound fell deservedly into disrepute. It was found, however, that simply by heating the moulds before filling, and pouring the fat at a temperature only just sufficient to maintain it in the fluid state, the fat solidified in a regular manner. On leaving the hot closet, the frame, the progress of which we are following, arrives at a cistern containing the melted fat, kept at the proper temperature by means of a coil of pipe filled with steam. A man then opens a hatch, when the fat flows out through as many holes as there are moulds to be filled: the fat flows into the moulds, completely filling them, as well as the trough into which their open ends are inserted. The fat soon solidifies. A boy then detaches the forceps, which kept the wicks tightly strained; scrapes out the superfluous tallow from the trough, by means of a wooden wedge; moves the frame into a little carriage at the further end of the line in which it was filled, and then wheels this carriage to the further end of the line from the near end of which we started. Other frames, succeeding the one we are following, push it forward until it gets back again to the place

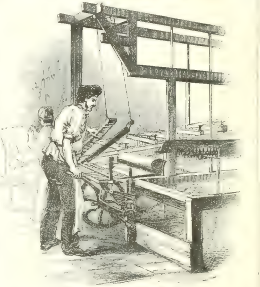


Fig. 428. MOULDING-FRAME.

from which we commenced. The man then takes hold of the frame, lifts it up into a horizontal position, moves a lever, which operates upon a set of ramrods provided with a spring-catch, which lays hold of the mould tops, and pushes them, with the candles attached, through the moulds; and thus, by a single operation, one set of candles is drawn and the wicks for the next set inserted. The candles thus ejected in parallel lines are received upon a grooved board; a board covered with flannel is brought down upon them; the spring forceps are inserted, to hold the wicks securely; and a circular knife passed between the candles, and the forceps finally separates the made candles from the wicked moulds. The candles are then removed; the frame is transferred from the left to the right-hand line of rails, and the round of operations commences as before. It is stated that in each set of moulding-frames constituting a candle-machine there are, when first cottoned, 9½ miles of wick; so that, if the six machines contained in this department were started at once, above 500 miles' length of candles would be made in exhausting one single wicking of the machines.

The candles, as they are released from the moulds by the drawing-machine, are conveyed in boxes to the packing department, where they are put up in sealed packets with great rapidity. The people are so accustomed to this work that, whatever be the number of candles required for one packet, they take them with one grasp from the heap, without any kind of mistake.

The manufacture of *night-lights* is a very important feature in this establishment. A night-light consists of a very short thick cylinder of fat, with a very slender wick, and is calculated to burn for 6, 8, 9, or 10 hours. There are three kinds of night-lights, namely, *Patent Alberts*, *Child's night-lights*, and *Price's patent night-lights*. The first are formed in a metal frame, containing a number of cylindrical holes: at the bottom of each hole is a projecting wire, which moulds a narrow hollow tube for the wick, which is inserted by an after process. The trough containing the cylindrical holes is filled with the melted fat, as shown in Fig. 429. When this has become solid, the superfluous fat is scraped off: a man then depresses a lever, which causes the bottoms of the moulds to rise and eject the cylinders of fat. The wicks are then inserted, with marvellous rapidity, by a number of children. Each wick is stiffened with wax, and has a small piece of tin as a support at the bottom. The wick is put through the hole, and the tin cemented to the bottom by dashing it down upon a small glazed earthenware vessel, kept hot by the burning of a light within. These lights are burnt in glasses similar to a fluted straight-sided wine-glass. Judging from the number of little lads employed in "wicking," there must be a great demand for these lights, which is certainly justified by the whiteness and clearness of the material, the absence of smell of any kind, their elegant appearance while burning, and their perfect safety.

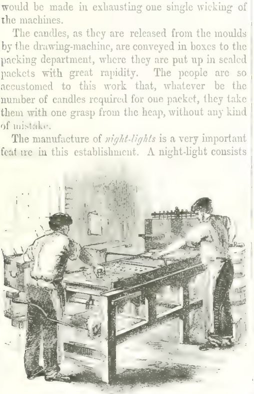


Fig. 429.—[illegible] NIGHT-LIGHTS.

In the preparation of *Child's night-lights*, a paper box like a pill-box, with a hole in the bottom, is first made: into this is inserted a waxed wick, provided with a tin support at bottom; the box is then filled up with material, and put out on boards to cool. This is apparently a simple process; but it requires considerable care and accuracy. Great difficulties were originally experienced in compounding the material, and in regulating the small wick, so as to burn the required time in both warm and cold weather. In using these lights, they are placed in a saucer containing water to the depth of about one-eighth of an inch, not only for the sake of security, but also to keep the bottom cool, and thus prevent the fat from running out of the case.

Price's patent night-lights are made like the last, but of a somewhat cheaper material, which has been patented. They are intended to be introduced among the working classes, and to be sold at the cheap rate of two for a penny. At the time of our visit, the manufacture of them had just commenced.

We were shown the building appropriated by the Company to the manufacture of night-lights; and when it is stated that it is 180 feet long by 100 wide, some idea may be formed of the extent of this branch of manufacture.

In concluding our notice of this factory, it should be stated that everything seems to be in perfect order; the health, comfort, and convenience of the numerous workpeople are consulted; there is an excellent school for the children, who attend a certain number of hours every day. The furnaces consume their own smoke, and are adapted to the burning of the refuse coal of the market. Connected with the establishment is a laboratory, an engineer's workshop, carpenters', tinmen's, coppersmiths', and weavers' shops, forges, a cooperage, a sealing-wax manufactory, and a steam printing-machine, for printing labels, &c. The buildings are waterproof; and the smell of the manufactured material reminds the visitor of violets rather than of tallow. [See APPENDIX.]

We may appropriately conclude this article with a few remarks on the chemistry of a candle. Flame has been defined to be a luminous bubble of gaseous matter. It is not, however, necessarily luminous; for the flame of pure hydrogen has but little illuminating power, although its heat is great. If, however, we project into the hydrogen flame solid matter in a minutely divided state, such as charcoal dust, steel filings, oxide of zinc, magnesia, &c., the solid particles become white-hot in passing through the flame, and greatly improve its luminosity. In the flame of our candles, lamps, and gas-lights, hydrogen supplies the heat, and minutely divided carbon the light. A candle is a simple but ingenious contrivance for supplying the flame with as much melted fat as it can consume without smoking; and, to produce this effect, the wick must bear a certain proportion to the thickness of the candle. If the wick be too large, too much tallow will be melted, and the candle will gutter; if too small, too little tallow will be melted, and the flame will gradually be inclosed within a circular wall, which being from time to time undermined by the heat, will fall down, and also cause the candle to gutter. In night-lights, there is indeed a small wick and a great thickness of tallow, whereby a deep and full reservoir of melted fuel is formed; but this is prevented from escaping by the paper mould which surrounds it. If the thickness of the candle be properly adjusted to the size of the wick, the tallow immediately below the flame is melted into the form of a hollow cup, which forms a reservoir always properly filled for feeding the flame. The fibres of the twisted wick act as a congeries of capillary tubes, which convey the fluid fat into the flame, where, being exposed to a high temperature, and sheltered from the air by the outer shell of flame, it becomes subjected to a dry distillation. The inflammable vapour thus produced rises, and, by constant combustion, diminishes in quantity, and consequently in diameter, until at length it entirely disappears in a point.

We have spoken of flame as a luminous bubble or shell, because it is in fact a hollow body, the exterior only being luminous, where the contact with the air produces perfect combustion. A current of air, set in motion by the heat of the flame, causes fresh air constantly to stream up from below: the oxygen of the air, aided by the high temperature, decomposes the inflammable vapour of the fat into hydrogen and carbon: the hydrogen burns, or, in other words, unites with the oxygen of the air, and forms vapour of water: the carbon at the same moment is set free, becomes white-hot, and imparts luminosity to the flame, but it does not disappear from the scene of action until it gets to the exterior of the flame, where the oxygen of the air seizes it, and forms with it carbonic acid.

The flame of a candle, Fig. 430, consists of four tolerably distinct portions:—1. the dark interior, containing unburnt combustible vapour; 2. around this the brilliant part of the flame, or the flame properly so called, where the hydrogen is united with the oxygen of the air, and the carbon, not having yet done so, is in an incandescent state; 3. beyond this another film or casing, where the oxygen of the air unites with the carbon; 4. the blue portion at the bottom of the flame, where the inflammable vapour undergoes perfect combustion, and no solid carbon is deposited to afford light. In some cases there is, 5. a slender cone of a deep red colour, arising from an excess of carbon, which escapes unburnt, or nearly so, at the top of the flame, and cooling below a white heat, diminishes the light. This, however, never takes place in a well made candle. In this, on the contrary, the hottest part of the flame is just at the top of the luminous cone, where combustion is perfect, and the air not sufficiently in excess to carry away the heat so quickly as at the sides, or in the blue part at the bottom.

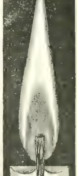


Fig. 430.

The portion of the wick within the flame is charred by the heat, but not consumed, on account of the absence of air. In a common candle it is evidently not consumed, or those troublesome and untidy implements, snuffers, would be unnecessary. In course of time, however, if the candle be left unsnuffed, the wick will project beyond the flame, and coming in contact with the air, be partly consumed; but the soot, collecting as a spongy mass at the top, will darken the flame, and at length, falling into the cup, will break down its edges, and cause the tallow to overflow. In wax, stearine, and sperm candles, this defect is avoided by plaiting the wick, or by giving it a greater twist, by which means the end is caused to bend considerably, and thus, protruding out of the flame, is consumed.[1] If this method were adopted with tallow candles, it would only produce guttering. In Palmer's candles, the wick is in two parts, and, by a particular twist given to each, and by winding a thin wire round each, they are made to fall asunder like a fork, when both ends, constantly protruding through the flame, are consumed.

The properties of flame, as above stated, may be illustrated by a number of beautiful experiments. To prove, for example, that the combustion is superficial only, and that the flame is a film of white-hot vapour, enclosing an interior portion, which cannot burn for want of oxygen, bring down upon the flame of a candle a piece of thin glass, so as to make a transverse section of the flame: we shall then observe a ring of light surrounding the interior dark part of the cone. This experiment may be still better performed by means of a piece of wire-gauze, about nine inches square, and of such fineness as to have about thirty meshes in the square inch. When this is gradually

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(1) According to Dumas, stearine candles always retain a minute portion of lime, which would clog the wick, and diminish its capillarity, unless the precaution be previously taken to pass the wick through a solution of boracic acid: this forms with the lime a borate, which becomes fixed in the wick, and is converted into a fusible bead, which may be seen at the end of the wick after its complete combustion.

brought down upon the flame of a large and steadily burning wax candle, the flame will be cut off where it touches the gauze, and the exterior luminous circle will be well defined, Fig. 431. The inflammable matter of the flame will pass through the gauze in the form of smoke; its temperature being so far cooled in its passage through the meshes as to be incapable of passing through as flame. It is on this principle that the safety-lamp of Sir Humphry Davy serves as a protection in coal-mines. [See Coal.] The inflammable vapour which passes through the wire-gauze can, however, be kindled by the direct application of flame, as in Fig. 432. These experiments are well exhibited with a jet of gas, issuing under low pressure. If the gauze be held over the jet before it is lighted, and a flame be applied above, it will take fire there, and the gauze will prevent it from passing through, so as to kindle the lower half. (See Fig. 433.) Place a piece of camphor on the centre of the wire-gauze, and apply a flame below: the camphor will melt, and pass through the gauze, burning only on the under side, as in Fig. 434.

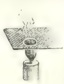
Fig. 431.

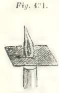
Fig. 432.

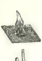
Fig. 433.

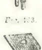
Fig. 434.

The cooling power of wire-gauze may be referred to its good conducting power: it also becomes by use an excellent radiator of heat. That flame is extinguished by cooling it may be shown by bringing a large mass of metal near a very small flame, or by carefully surrounding it by a coil of wire. The metal abstracts its heat, and extinguishes the flame. When a cold surface is held over a large flame, a portion only of such flame is destroyed, and the carbon of the inflammable vapour is deposited in the form of a minutely divided soot on the cold surface. That no combustion goes on, or can go on, in the centre of flame, may be shown in various ways; as, for example, if we kindle spirit of wine (which does not deposit carbon) in a small saucer, and place a rod of white wood across it for a few seconds: it will be found on removing the wood that it is burnt or blackened only at two points, where the flame was in contact with the air, Fig. 435. We may even place gunpowder, contained in a small circular spoon, or even at the end of a small knife, within the flame, and it will not be kindled. Phosphorus under similar circumstances will fuse, but not take fire, and oil of turpentine, in a small thimble, will become vapour, which will burn only at the upper part of the flame, where it is in contact with the air.

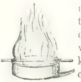
Fig. 435.

It will be understood, then, that the interior dark part of the flame contains inflammable vapour, which will not itself support combustion. This inflammable vapour may be drawn out of the flame and ignited at a distance from it, by inserting one end of a small glass tube into the flame of a large candle, *f*, Fig. 436: *p* is the glass tube held in an inclined position in the centre of the flame, and *g* is the inflammable vapour ignited at its extremity.

By propelling a current of air through flame, as in the blowpipe, we supply oxygen to the interior, and enable combustion to go on there as well as at the exterior, by which means the heat of the flame is greatly increased. The Argand burner acts somewhat in the same manner.

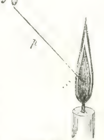

Fig. 436.

CANNON, see Casting and Founding—Boring.

CANVASS, a woven fabric, made from the fibres of hemp. The word is said to be a corruption of the Latin name for hemp, *cannabis*. The Italians call it *canape*. A finer description of canvass, called *huckaback*, is made from hemp, for towels and common table-cloths. [See Hemp—Floor-cloth—Weaving.]

CAOUTCHOUC. This very remarkable substance (also called *elastic resin*, or *India-rubber*,) is produced from the syringe-tree of Cayenne and other parts of South America. For the first knowledge in Europe of the source of caoutchouc, we are indebted to some French academicians, who were sent out for the purpose of astronomical observation, in 1735. They discovered that it was the white milky juice of certain plants, found abundantly in Para, in the Brazils, in Quito, and since found in Asia. Of late years, considerable quantities have been brought from Java, Penang, Singapore, and Assam. The trees grow so abundantly in some places, that hundreds of miles are covered with them. Caoutchouc oozes out as a vegetable milk from incisions made in the tree: it is collected chiefly in wet weather, when it flows most abundantly. The methods of inspissating and indurating it are kept secret: it appears, however, that the juice thickens and hardens gradually on exposure to the air, and that, as soon as it becomes solid, it displays an extraordinary degree of flexibility and elasticity. Hence it is supposed that the natives make moulds of clay, or some substance that can be easily broken, and cover them repeatedly with layers of the juice, allowing each layer to dry before the next is applied. When the proper thickness is attained, the mould with its elastic covering is held over the smoke of a wood fire. The mould is then broken out, and the dried bottle forms the India-rubber of commerce. Mr. Solly, in a paper on the preparation of caoutchouc, (*Trs. Asiatic Soc., London,*) adverts to the manner in which the sap is prepared for the market, by being laid on to some substance in successive layers, which are allowed to dry. That such is the case is evident on cutting a bottle of caoutchouc: the layers are distinctly visible, and they may even be separated if the mass be soaked in boiling water. It is evident that a great quantity of impurities must be deposited on the surface, and thus diminish the force with which the layers adhere to each other, thereby taking away considerably from the value of the substance. In large masses of fresh caoutchouc, a great number of cavities filled with a brown liquid may be discovered, and these of course diminish its strength. Mr. Solly proposes that the sap as first procured should be washed with water: that which separates may then be pressed, and will be found very much stronger than if it had been prepared without the washing.

The Indians make waterproof boots of this substance, which, when smoked, have the appearance of leather. Bottles are also made of it, to the necks of which are fastened hollow reeds, so that the liquor contained in them may be squirted out at pleasure. One of these filled with water is always presented to each of the guests at their entertainments, who uses it for syringing his mouth; a custom which led to the term *seringat*, or *syringe*, being applied by the Portuguese to the tree and its resinous production. The natives also form this substance into tubes about 2 feet long, and 1½ inch thick, which they use as torches: they give a good light, emit but little odour, and are said to last about twelve hours each.

The juice of this tree has been sent in bottles to this country. It is of a pale yellow colour, and creamy, and contains a portion of deposited caoutchouc. It has a sourish and slightly putrid odour, and a sp. gr. of 1.0117. When spread upon a solid body in thin layers, it forms an elastic deposit. It contains about 32 per cent. of caoutchouc, with a little albumen, wax, and gum, and a brown, bitter, azotised substance, soluble in water and in alcohol. When this juice is heated, the caoutchouc coagulates, and envelops the albumen. To obtain pure caoutchouc, the fresh juice must be mixed with water, and left for twenty-four hours, when the suspended caoutchouc collects on the surface in the form of a cream, which is removed, and washed repeatedly, until nothing further is separated by water: the finely divided caoutchouc is then separated from the water by the addition of a little salt or muriatic acid, and is dried at a gentle heat: as the water evaporates, the particles cohere.

The sp. gr. of caoutchouc is about 0.925. It is made hard but never brittle by cold. When boiled in water or alcohol it swells and softens, and in that state is readily acted on by those substances which dissolve it, but it is insoluble both in water and alcohol. It is soluble in washed ether, which, however, rejects the sooty and albuminous impurities, so that by precipitating a clear etherial solution by means of alcohol, the caoutchouc may be obtained in its milky form. It also dissolves in sulphuret of carbon. In cold naphtha, caoutchouc swells up into a soft pasty mass, most of which is dissolved by the further addition of naphtha assisted by heat. It also dissolves in the rectified empyreumatic oils of coal and of wood, and in the oils of turpentine, lavender, and sassafras. It is softened by and partly soluble in other volatile and many of the fixed oils, forming viscid and glutinous compounds, not drying into an elastic state, as it does on evaporating the solutions made with the above-named volatile oils, &c. A varnish well adapted for making shoes, &c. watertight, may be obtained by boiling 4oz. of caoutchouc in 1¾lbs. of linseed oil until perfectly dissolved, and then passing through a strainer. The caoutchouc is to be cut into strips, and well stirred during the boiling with an iron spatula. The solutions of caustic alkalies, chlorine, and bromine, have no action on caoutchouc. Nitric acid renders it yellow, and when assisted by heat decomposes it: it is also charred on the surface by sulphuric acid. According to Faraday, the ultimate composition of caoutchouc is—Carbon 87.2, Hydrogen 12.8.

Caoutchouc melts at 248°, but when exposed to a heat of about 600°, it is resolved into a vapour which may be condensed by cold into a remarkable liquid, which has been called *caoutchoucine* or *caoutchisine*. This substance was discovered by Mr. W. H. Barnard, in the course of some experiments on the impregnation of ropes with caoutchouc, at the factory of Messrs. Enderby at Greenwich. In 1833, Mr. Barnard obtained a patent for the invention of caoutchisine, "a solvent not hitherto used in the arts." His method of preparing it is to cut common india-rubber into lumps, each containing about 2 cubic inches: these are thrown into a cast-iron still S, Fig. 137, with a cover C, ground to a metallic fit to admit a thermometer to take the temperature. F the fire-place and ash-pit, E the worm-tub and worm, R a roller, and chain C, in conjunction with a crane, or other means for raising the cover to take out the residue and to charge the vessel. Heat is applied until the thermometer indicates a temperature of 600°. As this temperature is approached, a dark-coloured oil or liquid is distilled over, and nothing remains in the still but dirt and charcoal. The distillation is greatly facilitated by the addition of a portion of this oil, either previous or subsequent to the rectification, in the proportion of ⅓ oil to ⅔ caoutchouc. The dark-coloured liquid thus distilled is rectified, whereby fluids are obtained varying in sp. gr. the highest of which is about .670. At each rectification the colour of the liquid becomes more bright and transparent, until at the sp. gr. of about .680, it is colourless and highly volatile. In the process of rectification for the purpose of obtaining a larger product of the oil colourless, about ⅓ of

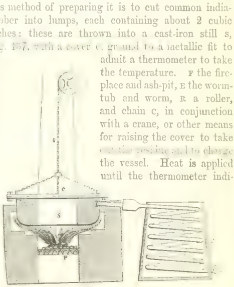

Fig. 137.

water is put into the still. In every state the liquid is a solvent of caoutchouc and several resinous and oleaginous substances, and also of other substances, such as copal in combination with very strong alcohol. The dirt which adheres to the bottom of the still is with difficulty removed: but the inventor adopted the ingenious contrivance of throwing into the still a solder of lead and tin to the depth of about half an inch, and as this became fused, the dirt on its surface was easily removed. The smell of the liquid thus obtained by distillation can be removed by mixing and shaking up the liquid with nitro-muriatic acid or chlorine, in the proportion of a quarter of a pint of the acid to a gallon of the liquid.

Cordage steeped in caoutchisine was found to be remarkably supple and tenacious: water-proof cloth was also prepared by its means, as also some excellent varnishes. The residue left in the still was also found well adapted to the formation of pitch or tar, for the use of the ship-builder. Unfortunately, the high price of caoutchouc has imposed a limit on the general application of caoutchisine, and the other hydrocarbons obtained by the distillation of india-rubber. We therefore return to the more ordinary uses of caoutchouc.

Caoutchouc was not known in Europe until the commencement of the last century, and it continued for a long time in comparative obscurity.[1] It was first used for rubbing out the marks of black-lead pencils. Its use was then extended to the preparation of certain varnishes, which it rendered capable of resisting changes of temperature without cracking and scaling off. The facility with which two recently cut and perfectly clean surfaces of caoutchouc weld together, led to its use in the laboratory for the formation of short elastic tubes, which are used as connectors for a variety of apparatus, in which separate pieces of glass tubing are thus joined together with flexible joints: they are prepared by wrapping a piece of sheet caoutchouc loosely over a glass tube or rod, and then cutting off the superfluous portion with a pair of scissors, Fig. 438: on pressing the fresh cut edges together, they cohere so as to form a perfect tube. Caoutchouc is also used in the preparation of certain surgical instruments, which are required to be both supple and flexible. But the most important application of caoutchouc has been in waterproofing. In fact, caoutchouc is, as M. Dumas remarks, a very wonderful substance. None of the ordinary acid or alkaline caustics attack it: it may be bent in all directions and stretched to a remarkable extent, and returns to its primitive form when the bending or stretching force is removed, and it accommodates itself to all the variations of the surfaces to which it is applied. It may be cut into thin sheets and subdivided into threads and elastic bands: its elasticity can be taken away and restored again at pleasure: it can be cut and moulded in a thousand different manners, according to the caprices of fashion or the devices of invention: there is no waste, for all the shreds and fragments can be cemented together and used as effectually as a new piece.

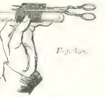

Fig. 438.

In the preparation of water-proof clothing there is, however, a defect. The caoutchouc by its solution in some of the essential oils is somewhat modified in character. It retains a portion of the oil, which softens it, and also imparts a certain odour. The problem which has yet to be solved, is how to render caoutchouc fluid, not by the use of oils, which cannot afterwards be entirely got rid of, but by restoring it to that emulsive state in which it flows from the trees which supply it. M. Dumas suggests that the sap itself should be imported in bottles or close vessels, absolutely air-tight, and in this state be prepared for the manufacture of water-proof garments. Or a solution in ether being made of the caoutchouc, the pure caoutchouc precipitated by alcohol should be spread over a piece of cloth properly stretched. A second piece of cloth should then be rolled over this with very strong pressure, and the result would doubtless be a perfectly waterproof cloth without any odour. Or the two pieces of cloth to be cemented together might be wound upon rollers moving together as closely as possible, and one of them heated to a certain temperature. The etherial solution of caoutchouc being allowed to fall upon the heated roller, the ether in evaporating would leave a thin layer of caoutchouc, which would be immediately covered over by the motion of the rollers. If this operation were conducted in a small close chamber, the vapour of ether might be conveyed away to act upon the india-rubber in process of solution. The loss of ether would thus be diminished. We fear, however, that the high price of alcohol, and consequently of ether, in this country, would preclude the adoption of either of these suggestions.

The ordinary method of making waterproof cloth is exceedingly simple. The caoutchouc is dissolved in the oil distilled from gas-tar, and spread upon the surface of a piece of cloth, upon which a similar piece is then extended. Both pieces are then passed between a couple of rollers. Hence the waterproof fabric consists of two pieces of cloth united by an interposed layer of caoutchouc. This cloth is so impervious to moisture that floating or hydrostatic beds are formed of it, and beds and cushions are rendered elastic by inflating them. This method of forming waterproof cloth was invented by Mr. Mackintosh of Glasgow, whose name has become so familiar by being applied to the articles formed of this fabric. One of the greatest objections to articles of this clothing arises from the very perfection of the protection

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(1) Few persons are probably aware of the comparatively late introduction of india-rubber into this country. Dr. Priestley in the preface of his work of Perspective, printed in 1770, says:— "Since this work was printed off, I have seen a substance [no name is given to it] excellently adapted to the purpose of wiping from paper the marks of a black-lead pencil. It must, therefore, be of singular use to those who practice drawing. It is sold by Mr. Nairne, Mathematical Instrument Maker, opposite the Royal Exchange. He sells a cubical piece of about half an inch for three shillings, and he says it will last several years."

against moisture which they afford. For as they allow no wet to pass through, they do not allow the insensible perspiration of the skin to pass out. Hence they become inconveniently warm to the wearer, and are doubtless injurious to health. In water-beds the absence of the necessary porosity of a common bed is strikingly shown by the condensation of the perspiration forming streams of water, which wet the bedclothes, and render the bed very uncomfortable.

Caoutchouc has been spread out into sheets by soaking a bottle of india-rubber as imported until quite soft. It may then be inflated by blowing into it until it has become so thin as to be transparent and sufficiently light to ascend when filled with hydrogen gas. If dried in this state it will not again contract, and thin sheets may thus be formed.

In the various fabrics which have been manufactured with caoutchouc as one of the constituents, the warp or longitudinal threads are of caoutchouc, and the weft or cross threads of cotton, silk, or linen, according to the object of the fabric. Elastic braid is made by a machine by covering a thread of caoutchouc with silk or other threads. The threads of caoutchouc are produced by cutting it by means of a machine with the greatest evenness and equality. One pound will make a thread (No. 5) 8,000 yards in length; but this thread may by the machine be again cut longitudinally into 4, making in the whole 32,000 yards from one pound of caoutchouc, and such is the facility obtained by the machinery that two girls are capable of cutting 30 lbs. per day, producing 240,000 yards of No. 5 thread. In working threads of caoutchouc it is found that if they be kept stretched for some length of time, and are exposed to cold, they become set to the length to which they have been stretched, and will no longer have elasticity. Consequently in weaving fabrics with warp threads of caoutchouc, the fabrics when first woven are not elastic, nor can they be extended to a greater length; but in order to impart elasticity to such fabrics, a hot iron is passed over them, whereby the warp threads of caoutchouc shrink back to their original length, and then become elastic. In some instances where the elastic fabric would be liable to be extended beyond the ultimate power of the elasticity of the caoutchouc, instead of having all the warp threads of elastic gum, alternate threads of cotton, silk, or linen are placed in the loom; by this means the fabric cannot be stretched beyond the ultimate power of elastic elongation of the caoutchouc, as the strain would then come on the warp threads of cotton, silk, or linen, and prevent the fabric being further stretched. Dr. Ure states that each thread is rendered inelastic while it is being reeled, by the tenter boy or girl pressing it between his moist thumb and finger, so as to stretch it to at least eight times its natural length, while it is drawn rapidly through between them by the rotation of the power-driven reel. This extension is accompanied with condensation of the caoutchouc, and with very considerable disengagement of heat. The reels, after being filled with the thread, are set aside for some days. The caoutchouc thread of the Joint Stock Caoutchouc Company is numbered from 1 to 8. No. 1 is the finest, and has about 5,000 yards in a pound weight; No. 4 has 2,000 in the pound weight; and No. 8, 700, this being a very powerful thread. The finest is used for the finer elastic tissues, as for ladies' silver and gold elastic bracelets and bands. The ropes made with the strongest of the above threads, covered with hemp, and their elasticity restored by heat, possess extraordinary strength and elasticity.

Numerous patents have been taken out from time to time for improvements in the manufacture of caoutchouc. Among others we may notice Mr. C. Nickel's patent, granted in October, 1836, and which, we believe, includes Mr. Sievier's process. The caoutchouc is first cut into small portions, and well washed in hot water to remove any dirt or impurities, and the cuttings are then dried at about 200° in iron or other vessels heated by steam. The cuttings thus cleaned and dried are next passed through a pair of iron rollers, by which they are blended and pressed together. The caoutchouc is then put into a mill consisting of a roller covered with spikes moving within a hollow spiked cylinder, and ground until it becomes equally and uniformly mixed. During the grinding, great heat is disengaged; and although the water be let in cold, it soon becomes boiling hot, and emits copious vapours. When no water is admitted, the temperature rises much higher, so that the elastic mass of india-rubber, although a bad conductor of heat, cannot be safely touched by the hand. During this grinding, a quantity of muddy water runs off through apertures in the bottom of the drum. In the course of half an hour, the pieces become agglutinated into a soft elastic ball, of a reddish brown colour. This ball is removed to another drum, furnished with spikes or cutting chisels. Here the caoutchouc is kneaded dry, with a little quicklime. It now gets very hot, discharges in steam the moisture imbibed in the previous operation, becomes more compact, and deepens in colour. Dr. Ure, who inspected the process at the establishment of the Joint Stock Caoutchouc Company, at Tottenham,[1] says, that during this second grinding frequent explosions take place, from the expansion and sudden extrication of the imprisoned air and steam. From this second set of drums the ball is transferred to a third set, where it is condensed into a homogeneous solid. Seven of these finished balls, weighing 5lbs. each, are introduced into a larger drum, the shaft of which is studded with blunt chisels. There the separate balls are incorporated into one mass, free from cells or pores, and now fit to be squeezed into a rectangular or cylindrical mould, previously rubbed over with soap-water to prevent adhesion: here it is condensed into a solid block by the compressing action of a screw; but by Mr. Hancock's process this is done by inserting into the cylinder the piston or

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(1) "Supplement to Dr. Ure's Dictionary of Arts, Manufactures, &c." London. 1846.

plunger of a hydrostatic press. When the pressing is complete, the caoutchouc is left in the mould till it is cold, but still under pressure; it is then forced out of the mould. If it be desired to cut this block into sheets, it is raised out of the mould *m* very gradually by means of a screw, Fig. 439, which being turned, raises the proper quantity, which is ascertained by having a gauge of the thickness required, and when so much is forced beyond the end of the mould, that portion is cut off with a knife, a continuous stream of water being supplied to the knife or cutting edge to keep it cool. A hollow cylinder of caoutchouc may be formed by placing a solid core within the mould, and using a hollow piston or plunger, as in Fig. 440. Cylinders of ground caoutchouc may also be formed by means of pressing-rollers with equal and smooth surfaces. The ground caoutchouc directly from the mill is placed between the rollers, which by their revolution pass a continuous thin sheet through them. This is tightly wound upon a wooden roller as fast as the sheet is formed, by which means any degree of thickness may be obtained, and as the same is warm by passing between the rollers, the folds will cohere and become of one close substance.

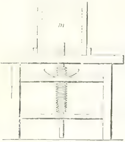


Fig. 439.

Fig. 440.

In order to form the caoutchouc into threads, the hollow cylinder is first cut up into tapes by cutting it from end to end in a spiral direction. The circular slices or discs may be cut into tapes in a somewhat similar manner, proceeding from the circumference to the centre, spirally. The tapes thus formed are cut into threads by means of the machine, Fig. 441, in which a series of circular knives *l* are fixed on an axis *m*, between two circular plates, one of which is capable of movement, and of being tightly fixed on the axis when the knives are in their places, there being a washer or disc of metal between every two knives for regulating the distance apart, according to the thickness of the thread required. The circular knives are 3 inches in diameter, and are made to revolve with considerable velocity; *n* is another axis, bearing a cylindrical block of hard wood, (such as wainscot oak,) against which the cutting edges of the knives come, and slightly cut into the block, which should be made of several parts or sections in order that the grain may run from the centre outwards in all directions. The axis *n* revolves but slowly in comparison with the cutters, as will be seen by the dimensions of the driving pulleys to each: the axis *m* making about 1,400 revolutions per minute, and the axis *n* only 24: *o* is a tape or sheet of caoutchouc being cut; it is guided between the pins *p*, and between the spring-guide plates *q*, there being a constant stream of water supplied to and amongst the knives by the pipe *r*. *s* is a piece of wood, in the cuts of which the knives work, and are thus cleaned, and any portions of caoutchouc which might otherwise remain between the knives are removed.

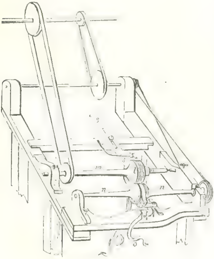


Fig. 441

Fig. 442 shows another arrangement for cutting a series of threads at one time. It consists of a number of discs of equal thickness, and of the thickness of the intended thread. They are fixed on two shafts or axes, which are geared together by cog-wheels, and between each pair of discs is placed a washer of the thickness of the intended thread. The upper and lower discs are so affixed on their respective shafts that they act between each other, and the sheet or tape of caoutchouc is conducted between the two sets of cutting discs. In other respects the arrangements are similar to those of Fig. 441.

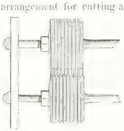
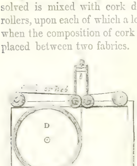


Fig. 442.

We may also notice some of the features of Mr. Walter Hancock's patent (sealed 9th November, 1843). In order to expose a larger surface to the action of the solvent, the india-rubber is cut into shreds by passing it between toothed rollers *a a*, Fig. 443, between which is a bar *b*, so that the rollers have the effect of shears in passing against the bar. The shreds thus produced are in some cases freed from impurities before applying the solvent, by washing them thoroughly. This greatly facilitates the manufacture of what is called *block-rubber* or caoutchouc, mechanically formed into large blocks for the purpose of cutting into small blocks or sheets.

Fig. 443.

Fig. 444 is a machine for flatting out the caoutchouc mixture upon fabrics. It consists of a frame supporting a pair of rollers, *r r*; *b* is a hopper, into which the material to be flatted into sheets is placed, and which is pressed down upon or between the rollers *r r* by means of a weight. The caoutchouc being dissolved is mixed with cork dust: *r r* are two outer rollers, upon each of which a length of cloth is wound, when the composition of cork and caoutchouc is to be placed between two fabrics. Motion being given to these rollers, the ends of the two separate lengths of cloth are brought from the outer rollers between the rollers *r r*, and secured around the drum D by one or more turns upon it, or by tacking them on. Motion being then given to the drum D, the cloth, with the compound delivered from the rollers *r r*, is wound upon it until the whole lengths of cloth are wound off the outer rollers on to the drum, from which it is removed to be dried. The thickness of the sheets of compound may be varied by adjusting-screws applied to the spindles of the rollers *r r*. When a very adhesive connexion with the cloth or fabric is desired, the cloth may be first covered with a thin coat of solution of caoutchouc, before the composition is milled or pressed between them. The surfaces may be ornamented by embossing them by means of pressure between plates, on which the desired pattern or design is engraved, or by passing them between embossing rollers. These surfaces may also be coloured by mixing any suitable pigment with a thin solution of caoutchouc, laying it on either before or after the surfaces are embossed. A piled surface may also be produced by using appropriate rollers, and for a very compact combination, the rollers may be raised to a blood heat. Small particles of leather or wood may be used with or instead of the cork dust.



F[illegible]

Mr. Hancock obtains a solution of india-rubber in ether, turpentine, coal-tar, oil, naphtha, or any other solvent, by introducing the solvent, in a state of vapour, into a vessel containing the India-rubber in small fragments: the vessel is exhausted of air, and kept at the desired temperature by means of a steam jacket.

The following description of the manufacture of waterproof double fabrics is from Dr. Ure's Supplement:—

"The wooden framework of the gallery in which the waterproof cloth is manufactured should be at least 50 yards long, to give ample room for extending, airing, and drying the pieces: it should be 2 yards wide, and not less than 5 high. It is formed of upright standards of wood, bound with 3 or 4 horizontal rails at the sides and the ends. At the end of the gallery where the varnish is applied, the web which is to be smeared must be wound upon a beam resembling in size and situation the cloth beam of the weaver's loom. The piece is thence drawn up, and stretched in a horizontal direction over a bar, like the breast-beam of a loom, whence it is extended in a somewhat slanting direction downwards, and passed over the edge of a horizontal bar. Above this bar, and parallel to it, a steel-armed edge of wood is adjusted, so closely as to leave but a narrow slit for the passage of the varnish and the cloth. This horizontal slit may be widened or narrowed at pleasure by thumb-screws, which lower or raise the movable upper board. The caoutchouc paste being plastered thickly with a long spatula of wood upon the down-sloped part of the web, which lies between the breast-beam and the above-described slit, the cloth is then drawn through the slit by means of cords in a horizontal direction along the lowest rails of the gallery, whereby it gets uniformly besmeared. As soon as the whole web, consisting of about 40 yards, is thus coated with the viscid varnish, it is extended horizontally upon rollers in the upper part of the gallery, and left for a day or two to dry. A second and third coat are then applied in succession. Two such webs or pieces are next cemented face to face, by passing them, at the instant of their being brought into contact, between a pair of wooden rollers, care being taken by the operator to prevent the formation of any creases or twisting of the twofold web. The under one of the two pieces, being intended for the lining, should be a couple of inches broader than the upper one, to insure the uniform covering of the latter, which is destined to form the outside of the garment. The double cloth is finally suspended in a well ventilated stove-room, till it becomes dry and nearly free from smell. The parings cut from the broader edges of the under piece are reserved for cementing the seams of cloaks and other articles of dress. The tape-like shreds of the double cloth are in great request among gardeners for nailing up the twigs of wall-shrubs."

Among other remarkable applications of caoutchouc, in combination with other materials, may be mentioned the paving of stables, lobbies, and halls with blocks of this substance. Some of the stables at Woolwich are thus paved, as are also the Admiralty court-yard, and the carriage-entrance court at Windsor Castle. Boats of india-rubber and cork have been proposed, such as shall be too light to sink, and too elastic to be broken to pieces. It has also been proposed to line ships of war with india-rubber, to prevent accidents from gun-shot splinters, and also to use this substance for hammock-nettings and bulwarks.

The combination of caoutchouc with sulphur produces what is called *vulcanized india-rubber.* The process of *conversion* consists in submitting india-rubber to the action of bisulphuret of carbon, mixed with chloride of sulphur. The caoutchouc cannot, however, be penetrated by this process to any depth, and therefore it is inapplicable when the mass to be acted on is thick. The process of *vulcanization,* invented by Mr. Hancock, is therefore adopted. When caoutchouc is immersed in a bath of fused sulphur, and heated to various temperatures, it absorbs the sulphur, assumes a carbonized appearance, and lastly acquires the consistency of horn. In the course of these changes, it attains the state of vulcanization which fits it for use. The same vulcanized condition can, however, be produced either by kneading the india-rubber with sulphur, and then exposing it to a temperature of 190°, or by dissolving the india-rubber in any known solvent, as turpentine, previously charged with sulphur. The effects of this treatment are—1st. the india-rubber remains elastic at all temperatures, while in its ordinary state it is quite rigid at a temperature of 10°; 2d, vulcanized caoutchouc is not affected by any known solvents, as bisulphuret of carbon, naphtha, or turpentine; 3d, it is not affected by heat short of the vulcanizing point; 4th, it acquires extraordinary powers of resisting compression. Thus, a cannon-ball was broken to pieces by being driven through a mass of vulcanized caoutchouc; the caoutchouc itself exhibiting no other trace of its passage than a scarcely perceptible rent. The applications of this substance are very numerous. The most familiar example is in the elastic rings and bands now so common. The same substance, adjusted in size and strength to the purpose required, furnishes springs for locks and for the racks of window-blinds. It is also capable of being moulded into the most intricate ornaments; its characteristic elasticity removing all embarrassment in relieving the undercut parts. It furnishes impervious bottles for volatile substances like ether, as well as an excellent inkstand. It is adapted to protect from corrosion wires subjected to the action of the sea, as in the case of the wires required for the electric communication between England and France. For the same reason, air-tubes of vulcanized rubber are better suited for life-boats than those made of canvass, which are liable to be destroyed by the action of the water. A similar tube has been used with success as a substitute for an iron band as the tire of a carriage-wheel, forming, in fact, a noiseless wheel instead of a noiseless pavement, such as wood. A vehicle so arranged is said to run easier than on the present plan. Library chairs on an uncarpeted room may be made noiseless by attaching discs of vulcanized rubber to the bottoms of the legs, and slamming doors may be rendered much less noisy by attaching strips of the rubber to the parts where the door and the door-sill meet. Both these plans have been recently adopted in the reading-room of the British Museum, much to the comfort of the students. Vulcanized rubber has been applied with success in the construction of railroads and railroad carriages. In the former it is laid between the rail and the sleeper, and thus prevents the rails from indicating any traces of pressure; and the springs connected with the buffers of the latter, when formed of this substance, can neither be broken, nor can their elasticity be surmounted, by any degree of concussive violence. In a lecture on this substance, delivered at the Royal Institution in April, 1847, the lecturer, Mr. Brockedon, exhibited objects illustrative of the great physical change induced on caoutchouc by vulcanization. He showed a screw with its recipient, both made of this substance, as well as a form of letter-press, (like a stereotype page,) for printing. He also noticed its usefulness in making epithems for surgical purposes, gloves and boots for gouty persons, &c. [See APPENDIX.]

CAPERS, the unexpanded flower-buds of the caper-tree, (*Capparis spinosa*,) a trailing shrub, growing in Italy and the south of France. Preserved in vinegar, these flower-buds constitute a well-known article of commerce, and of luxury at our tables. The cultivation of the tree for this purpose is confined to a comparatively narrow district in the south of France, namely, Cuges and Roquevaire, in the department of the Bouches-du-Rhône, and Olioulles, in the department of Du Var. The gathering time is from June to August. As soon as the morning dew is off the trees, women wearing a sort of flexible basket at their waists, collect the buds, at the rate of twenty-five or thirty pounds' weight in a day. The plantations are divided into compartments, each of which is visited every week during the season; an experienced picker being able to tell the precise day when the buds will be in the best condition. A small and choice form of bud is called the *nonpareil;* but if this be neglected for one day, it becomes a second-rate bud, called *capucine;* if not gathered then, it becomes on the third day a *capote.* These three qualities are perfectly well known to merchants, and are more esteemed than buds gathered at random. But the less scrupulous cultivators are not only careless in this respect, but often allow the flower to ripen its fruit, which is a kidney-shaped seed, and which is sold with the commoner sorts of capers. An inferior sort of caper is sold as *flat capers.*

In some cases, capers are exposed to the air before pickling; but the best way is to plunge them in vinegar at once, change the vinegar in a week's time, and then fasten up the cask, and keep it undisturbed until the sale. The finest vinegar should alone be used.

The caper sales take place about the month of September, and on the day fixed for the delivery of the capers, the vinegar is drawn off, and they are set in baskets to drain. They are then weighed, and delivered to the merchant, who usually takes them away in large casks, into which he returns the vinegar in which the capers have been preserved, which is ceded to him as a sort of perquisite when the sale is completed. Capers are exported to most parts of Europe. Our own consumption is not very large. not more than about 60,000 lbs. In 1856 we imported 73,691 lbs., including the pickle.

CAPILLARY ATTRACTION. If the extremities of tubes of very fine bore be immersed in water, the water will ascend in them to a certain height, which is great in proportion to the narrowness of the bore of the tube. Such tubes are called *capillary,* from their bore being not much thicker than a *hair,* and this form of adhesion is therefore called *capillary attraction.* The surface of the little column thus suspended will be a hollow hemisphere as at a, Fig. 445. If the same tube be plunged into mercury, the liquid instead of rising above, will be depressed below the general surface as shown in *b*, Fig. 446, and the surface of the mercury will be convex instead of concave. This effect will also be produced in capillary tubes plunged in water, provided the water cannot wet the tubes, as when they are covered with a thin film of oil, which prevents the adhesion.

"The phenomena of capillary attraction and repulsion, may also be seen in vessels containing fluids. If the fluid be capable of wetting the sides of the vessel which contains it, it will be raised and become concave all round the sides, as may be seen in a glass of wine or a cup of tea, and as shown in Fig. 445, *a;* but if the glass or cup be too full, the absence of lateral attraction by the vessel, and the predominance of the force of cohesion from within, will give the liquid a rounded form. If the vessel cannot be wetted by the fluid, as when it is greasy, or mercury be used, the fluid will be depressed all round the vessel and have a convex surface, as in Fig. 446. Some curious appearances of attraction and repulsion are produced by the operation of *capillarity* (under which term all effects depending on the adhesion of fluids to solids are now included). Two balls of pith or wood, either both dry or both wet, floating in water, attract each other as they do in all cases when so distant that it matters not whether the surface be raised or depressed where it approaches them; but if one ball be wet and the other dry, they repel each other as soon as the liquid surface which separates them is covered. All these effects have been made the subjects of deductive science and with great success. They have been generalized by Clairaut into the following law:—If the *intensity* of the attraction of the solid on the fluid be *greater* than *half* that of the fluid on itself, the fluid will *elevate* itself above the solid; if it be *less*, it will *depress* itself; and if it be *equal*, it will neither elevate nor depress itself."[1]

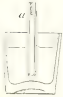


Fig. 445.

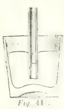


Fig. 446.

Examples of capillary attraction are very numerous; such as the ascent of water in a piece of lump-sugar, or in a sponge, the pores of the sugar or of the sponge acting as capillary tubes; the ascent of oil in a lamp and tallow in a candle, the cotton fibres of the wick serving also as fine tubes. The facility with which water becomes diffused among sand is also due to this cause. Sap ascends in plants by the same force, and some idea of its intensity may be gained by fitting a dry plug of wood tightly into a stout tube of glass or porcelain. If a projecting portion of the wood be allowed just to dip into the water, the liquid will ascend and cause the wood to swell with such force as to burst the tube, although capable of resisting a pressure of more than 700lbs. on the square inch. Advantage is taken of this property in the formation of millstones. A mass of stone is cut into a cylinder several feet high, which is subdivided into horizontal pieces, so as to make as many millstones, by chiselling out horizontal grooves quite round the cylinder, at distances corresponding to the thicknesses intended to be given to the millstones: wedges of wood are driven into this groove: these are then wetted, and the next morning the different pieces are found separated from each other by the expansion of the wood, consequent on its absorption of moisture, "an irresistible natural power," as Sir John Herschel remarks, "thus accomplishing almost without any trouble and at no expense, an operation which, from the peculiar hardness and texture of the stone, would otherwise be impracticable but by the most powerful machinery or the most persevering labour."

An interesting class of phenomena has been discovered by M. Dutrochet, which have a great analogy with those of capillarity. When two different liquids are separated by a porous partition, such as an animal or vegetable membrane, a motion is induced through the pores of the membrane of one liquid towards the other: this is termed *endosmose*, or "current towards the interior." Thus, if a vessel be divided into two distinct parts by means of a membrane, and water be poured into one part and a solution of gum in water, or acetic or nitric or muriatic acid, into the other, there will be endosmose from the water to the solution of gum, and to the acids respectively. There is no endosmose from one portion of liquid to another portion of the same kind of liquid, nor from water to a dilute solution of sulphuric acid. Sugar in solution of the same density with solution of gum gives a double elevation of the gum. Of all vegetable substances sugar exhibits the strongest force of endosmose, as does albumen among animal substances. The term *exosmose* is applied to phenomena the reverse of endosmose: it is due to the same cause, but has another direction.

Some very striking effects of endosmose and exosmose may be exhibited with some of the gases. For example; confine a portion of common air in a tumbler or wide-mouthed jar by carefully tying over it a piece of thin sheet india-rubber, and place it under a large bell glass filled with hydrogen and standing in a dish of water: the hydrogen will gradually find its way through the india-rubber and act upon it with such elastic force as to distend it and ultimately to burst it. If the included jar contain hydrogen, and the bell-glass, air, an opposite result will be obtained; the india-rubber will become concave instead of convex. This subject, however, is not of a sufficiently practical nature to be further noticed in a work of this kind.

CAPS, see PERCUSSION CAPS.

CAPSTAN, (French *cabestan*,) a vertical WINDLASS employed on board large vessels in the operation of weighing anchor, and for otherwise assisting the mechanical power of the crew. It consists of a drum or barrel revolving on a verticle spindle, with holes cut in the upper part or drum head for the

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(1) Tomlinson's Introduction to the Study of Natural Philosophy, published in Weale's Rudimentary Series, 1848.

reception of horizontal levers or *capstan bars* used for turning it round. The cable, or in large ships a smaller rope attached to the cable, called the *messenger*, is wound two or three times round the barrel, and as the capstan is turned round by men at the capstan bars, another set of men take in the

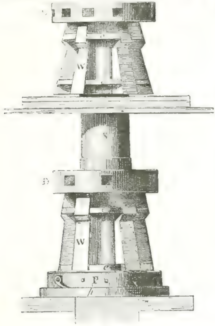

Fig. 447.

slack of the cable or messenger as it unwinds from the barrel. This machine was introduced into England in the reign of Elizabeth, and was probably obtained through the French from the Spaniards or Portuguese, who, from the use of the word *cabestante* in the second voyage of Columbus, appear to have been acquainted with it at least as early as the latter part of the 15th century. The machine has passed through a succession of improvements which need not be noticed here. The common capstan Fig. 447, consists of the *spindle* S, the *drum-heads* D, the *whelps* W, of which *c c* are the *chocks*, P is the *paul-head* and *p* the *paul-rim*. The *barrel* of the capstan is covered by the whelps, of which there are six to each capstan, and is made parallel from end to end: the whelps are bolted to the barrel, and the drum head is screwed down about an inch upon the whelps. The woodwork is made of well-seasoned English oak: the bars are usually of ash and about 10 feet long: they are inserted into holes mortised in the drum-head, 12 in the upper and 6 in the lower capstan, and they are secured by pins to prevent them from flying out by any recoil of the capstan; an accident which is guarded against by the use of pauls, of which there are two kinds; one bolted to the partners P′, that turn horizontally and are moved by hand: the other fastened to the paul-head and falling alternately into small iron cells in the paul-rim, and so disposed that the capstan cannot recoil above half the length of one of the cells without being checked by the pauls. The capstan is often made to consist of two parts attached one above the other to the same vertical axle, one being on the quarter-deck, and the other on the main-deck of a ship, both parts being turned by men who act against the bars of both at the same time. If there is a windlass on board ship, the lower barrel is dispensed with and the spindle is tapered gradually from the partners to the step. Sometimes the spindle is of iron, and runs down no further than the under side of the partners, where it is secured by a forelock.

In Captain Phillips's patent capstan, Fig. 448, W is the exterior wheel, which is fixed and is hung in the lower and after [illegible] c c, Figs. 449, 450, to prevent the motion of the ship from disturbing the machinery. B and C are two plates containing the centres of the pinions *p p*: into the top of these plates the bolts P P fall to increase the power; H H are bearings in the spindle, round the two lower of which the main deck capstan plays loosely, and the upper is the bearing in the quarter-deck partners; E is the centre pinion fixed on the spindle corresponding to F, Fig. 449, and *p p* are the pinions that act between W and F. At A, Fig. 450, is a hexagon on the spindle, over which the clutch-box I, Fig. 448, is fitted; K K are levers by which I is raised, to the outer ends of which the chains that carry the bolts P P are fastened, thus bringing into one action the two operations of separating the capstans and fixing the lower one to the machinery. The links O O are made to fasten to the hooks N N in the capstan head, as a method of keeping the clutch-box raised; Q Q are small bolts which can be pushed into the links of the chain M, to prevent, if necessary, the bolts P P from descending: when thus arranged, the capstans become separate and distinct

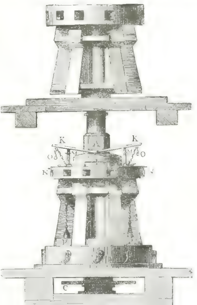

Fig. 448.

machines. By raising the levers K K the clutch-box falls, the bolts P P are suspended, and the whole becomes a common double capstan. Should any difficulty occur in raising the anchor, all that is necessary is to press down the levers so far as to hook the chain O, and the power is increased fourfold. "The reason of this is sufficiently obvious; the power applied to the upper capstan acts through the spindle upon the pinion, P, Fig. 449, which communicates its motion to that at *p*; now as this last turns about the teeth of the fixed wheel, it follows, that whatever force is exerted by P will be doubled at the centre of the pinion *p*, that is, will communicate itself with a double force to the lower capstan; and as it is necessary in calculating these effects to consider the power and weight as applied at an equal distance from the centre, we must suppose the power applied to the upper capstan to be half that which acts at the circumference of the centre pinion: that is to say, the power applied to the upper capstan is to that exerted at the lower as 1 to 4."

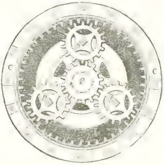

Fig. 449.

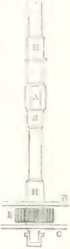

Fig. 450.

The capstan is superior to the windlass in point of expedition, because in the latter the levers must be shifted into fresh holes four times in each revolution: a larger number of men can also be employed at the capstan bars than at the handspikes of a windlass: but the men exert their strength more effectually at the windlass than at the capstan, since in the latter case they are employed to draw horizontally, when they exert a force of only about 35 lbs., whereas in the windlass, they apply their own weight at the extremity of the lever, and the average weight of a man is about 150 lbs. or 4 times his power of traction.

CARAT, a bean, the fruit of an Abyssinian tree called *kuara*. It varies very little in weight from the time of its being gathered, and is used as a weight for gold in Africa, and for diamonds in India. The carat consists of 4 nominal grains a little lighter than 4 grains troy. 74$\frac{1}{16}$ carat grains are equal to 72 troy grains. The carat is divided into halves, quarters or carat grains, eighth, sixteenth, and thirty-second parts. [See also ASSAYING.]

CARAWAYS, the seeds of *Carum carui*, a plant found in pastures over the whole of Europe, naturalized in England, and largely cultivated in Essex and Suffolk. The seeds, which are the furrowed halves of the ripe fruit, are used in medicine as a carminative, by confectioners and biscuit-bakers, and by the brewers' druggists as a flavouring for beer. It is a biennial plant, and is usually sown with coriander, and sometimes a crop of teazles is raised on the same land. By distillation with water, caraways yield about 5 per cent of a fragrant aromatic essential oil of a pale brown tint which deepens by age. It is a mixture of a hydrocarbon (*Carvine* = $C_{10} H_{8}$) and of an oxyhydrocarbon, which distilled with phosphoric acid yields a thick oil, (*caruole* or *caracole* = $C_{20} H_{14} O_{2}$).

CARBON, an elementary substance of first-rate importance in chemistry both organic and inorganic, and also in the Useful Arts. It is very widely diffused throughout the kingdoms of nature, and exists under an immense variety of forms. The purest form of carbon is the *diamond*, which is found throughout the range of the Ghauts in India, but chiefly at Golconda, in Borneo and also in Brazil. All the largest diamonds are from Golconda. The Brazilian mines are said to furnish from 10 to 13 lbs. weight of diamonds every year, of which not more than from 800 to 900 carats are fit for jewellery. It is always associated with materials transported from a distance, such as rolled gravel, so that its origin is doubtful. On removing the crust which covers the crystals, their exceeding brilliancy becomes apparent; they refract light powerfully and are generally perfectly transparent, although diamonds have been found of a black, blue, green, and of a beautiful rose colour. Those which are colourless are most esteemed: those which are slightly brown or tinged only with the other colours are least valuable. Black diamonds are extremely rare. The primitive form of diamond is the regular octahedron, or two four-sided pyramids, of which the faces are equilateral triangles, applied base to base, Fig. 451. It is also found in figures bounded by 48 curved triangular faces, but can always be cleaved in the direction of the faces of the octahedron, which possess that particular brilliancy characteristic of the diamond. The diamond is the hardest of the gems. Its sp. gr. varies from 3.4 to 3.6. It is a non-conductor of electricity; is not acted on by any solvent, nor is it affected by heat only, for it may be heated to whiteness in a covered crucible without injury: it burns in the open air at and about the melting point of silver, charcoal sometimes appearing on its surface, and it is entirely converted into carbonic acid gas. Attempts have been made to fuse or crystallize some pure form of carbon, or in other words to manufacture diamonds, but they have all failed. According to a recent experiment, when exposed to the very high temperature produced by a Bunsen's battery of 100 plates, or by a condensed mixture of carbonic oxide and oxygen gas, the diamond fuses, and is converted into a mass resembling coke: its sp. gr. is thereby reduced from 3.336 to 2.678.

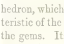

Fig. 451.

The combustibility of the diamond was ascertained by the Tuscan philosophers and the Hon. Mr. Boyle, who, by exposing a diamond in the focus of a large lens, consumed and dissipated it. It was also burnt by means of melted nitre in a gold tube by Mr. Smithson Tennant, and it was completely volatilized in the brilliant arch of flame evolved between charcoal points in the galvanic battery of the Royal Institution. Lavoisier proved that carbonic acid was evolved as a product in the combustion of the diamond and that of charcoal, a result abundantly confirmed by Messrs. Allen and Pepys and others. Sir George Mackenzie converted iron into steel by means of powdered diamonds instead of powdered charcoal. Mr. S. Tennant having placed a diamond in a gold tube supported in a state of incandescence, a stream of oxygen by means of gentle pressure was made to traverse it, and the result proved that the oxygen was converted into an equal volume of carbonic acid gas, which was found in an opposite receiver resting over mercury. Sir Humphry Davy when at Florence made some experiments with the Grand Duke's burning lens on the combustion of the diamond. 1.84 grains of small diamonds were placed in a platinum capsule, in a glass globe of the capacity of 14. 9 cubical inches, and supplied with oxygen gas, Fig. 452. "Soon after the capsule was placed in the focus in bright sunshine, the diamonds burnt with great brilliancy, and continued to burn until they had considerably diminished in bulk; but their splendour of combustion gradually became less, and before they had apparently lost half of their volume, the process ceased. By placing them a second time in the focus, after agitating the globe so as to change their places, the combustion was again produced; but the light was much less vivid than before, and the combustion continued for a much shorter time. They were exposed to the concentrated rays a third and a fourth time, but after the fourth time they seemed incapable of burning." The fragments which remained weighed .52 of a grain; they were not black, but were deprived of lustre. Sir H. Davy also ignited a small diamond weighing .45 of a grain, in a vessel of chlorine gas, and kept it in a state of intense ignition by directing on it the solar focus by means of the great lens of the Florentine Museum for more than half an hour: but the gas suffered no change, and the diamond had undergone no diminution of weight, and was not altered in appearance.

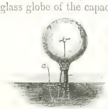
Fig. 452.

The art of cutting and polishing diamonds is supposed to have originated in Asia at some unknown period. It was accidentally discovered in 1456 by Louis Berquen, of Bruges, that by rubbing two diamonds together a new facet was produced. Diamond powder obtained by this rubbing is used for polishing the diamond. For the purposes of jewellery, the diamond is prepared by *splitting*, *cutting*, and *polishing*. The portions not required in shaping the stone are split off by fixing the stone in a ball of cement, about the size of a walnut: the line of division is then drawn a little way with a pointed diamond, fixed in another ball of cement: the stone is then split with the blunted edge of a razor, struck with a hammer. The small fragments removed, when too small for jewellery, are called *bort*. Diamonds are *cut* by the operation of one stone upon another. The stones are cemented in the ends of two sticks, supported on the edges of a small strong mahogany box, Fig. 453, about 4 inches long, 3 inches wide and 3 inches deep. The sides are half an inch in thickness, which gives it considerable strength. The upper surfaces of the four sides of the box are each covered by a rim of steel, and in the centre of each of the longest sides a pin of steel is firmly fixed: these pins are used as fulcra, against which the handles or sticks holding the stones are to be firmly pressed when in operation. The stones are then forcibly rubbed against each other, by which means they abrade each other in nearly flat planes, and remove a fine dust (*diamond powder*), which falls through the fine holes in the bottom of the box, and is there collected. By means of this powder diamonds are *polished*. An iron lap or *skive* being charged with diamond powder, the stone is guided by mechanical means: it is fixed by soft solder in a copper cup or *dop*, attached by a stout copper wire to the end of the *pincers*,—a flat board, terminating at the other extremity in two feet, which rest upon a fixed support; the whole forming a long and very shallow triangular stool, loaded at the end near the stone. The stone is readjusted for producing every separate facet.[1]

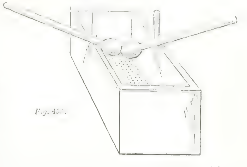
Fig. 453.

Diamonds are cut into various forms, called the *Brilliant*, the *Rose*, and the *Table*. The first form shows the gem to the best advantage, and is always set with the table upwards. In the rose the entire surface is covered with equilateral triangles terminating in a sharp point at the summit. This form is used when the spread of surface is too great for its depth, and it could not be cut into the brilliant form without great loss. The table is applied to such diamonds as may be regarded as plates, laminæ, or slabs, of small depth compared to their superficial extent. The brilliant and the rose lose in cutting and polishing somewhat less than half their weight, so that the value of a cut stone is double that of an uncut one, without reckoning the expense of the process. Small diamonds are sometimes set on black or coloured foil,

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(1) This subject will be resumed in the APPENDIX. See also LAPIDARY-WORK. The reader interested in the subject may consult Mr. E. Turrell's paper on splitting, cutting, and polishing diamonds, contained in Gill's "Technological Repository," 1827.

but a well-proportioned brilliant of extreme purity is best displayed when entirely exposed. The rose diamond is flat underneath, and its upper surface, raised in the form of a dome, is cut into facets. It has commonly six facets in the centre, triangular in shape, and converging to a point at their summit. The bases of these abut on another range of triangles in a reversed order, their bases being above, and conjoined with the bases of the higher facets, their points forming what are called *feuillets* or leaves. These last triangles have spaces between them, each of which is cut into two facets. The rose diamond is thus cut into 24 facets, and the surface of the gem is divided into two parts, of which the higher part is called the crown, and the lower part the teeth.

That part of the *brilliant* which rises in relief is always thinner than the *rose* diamond, and the entire thickness of the stone is divided into two unequal parts; $\frac{1}{3}$d is reserved for the upper surface of the gem, and $\frac{2}{3}$ds for the lower portion: this part, which is embedded and so far concealed, is called the *culasse*. Jeffries calls the lower flat part the *culet;* the superior one the *table;* the central line of the entire diamond the *girdle*, and the facets *skil* and *steel* facets. In a perfectly formed well-proportioned stone, the lower table should be $\frac{1}{5}$th of the upper table. The table has eight panes, and the circumference is cut into facets called *pavillons*. These should be placed in the same order as the upper facets, so that all false play of light may be avoided. The beauty of the brilliant depends on the sparkling splendour of its light, resulting from the high powers of refraction which distinguish this gem. The *rose* diamond darts a great splendour of light in proportion as it is more spread than the *brilliant*. The latter was an improvement on the *table* diamond introduced in the seventeenth century, and the advantage is caused by the difference in cutting it. It is formed into 32 facets of different figures, and inclined at different angles around the table upon the superior surface of the stone. The culasse is cut into 24 facets round a small table, which converts the culasse into a truncated pyramid. These 24 facets below, as well as the 32 above, are differently inclined, and exhibit different figures. The facets above and below must correspond perfectly, and the proportions be so exact as to multiply their reflections and refractions, so that the prismatic rays may be seen to the best advantage.

Fig. 454, No. 1, represents a regular octahedral diamond; No. 2, the top and bottom reduced, to form the table and collet; No. 3, the same, single-cut. No. 4 is a profile of a full-sized brilliant, in which *a* is the table, *b* the collet, *c* the girdle, *d* the bizet, and *e* the collet side. No. 5 is the table and bizet of No. 4: No. 6 the collet and collet side of the same. (Nos. 1 to 6 represent the sizes of brilliants of from 1 to 6 carats, cut in exact proportion.) No. 7 represents another brilliant. Nos. 11 and 12 are two views of a rose diamond: No. 8 table and bizet; No. 9 collet and collet side. Nos. 11, 12, 8, and 9 represent the size of a well-proportioned 10-carat diamond. Nos. 10 and 15 a table diamond; No. 13 a lasque; No. 14 the same, with one bevel.

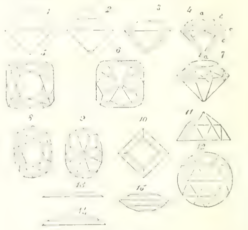

Fig. 454.

A, Fig. 455, is an instrument called by diamond-cutters *the compass*. It is formed of a piece of plain brass for the base, with a movable arm in the centre,

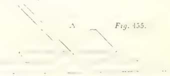

Fig. 455.

which in the figure is at 45°, measuring the inclination of the collet side to the girdle, and of the bizet to the table, at the supplement of the same angle.

The following are copies of some of the largest known diamonds. Fig. 456 is the Pitt or Regent diamond; the dotted line being the outline of the rough gem. This diamond is said to have been found in Malacca: it was purchased by Thomas Pitt, Esq. (grandfather of the first Earl of Chatham) when governor of St. George, in the East Indies, in the reign of Queen Anne, for 20,400*l.*; it weighed when raw 410 carats, and when cut 136½ carats. It was brought to London, cut as a brilliant, and sold to the Duke of Orleans for the king of France, in 1717, for 135,000*l*: 5,000*l.* was spent in the negotiation, &c. The cutting occupied two years, and is said to have cost 3,000*l.*: the fragments were worth several thousands, and the diamond has since been valued at 400,000*l.* Napoleon placed it in the hilt of his sword. It is still preserved among the jewels of France.

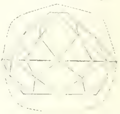

Fig. 456.

The Pigot diamond, Fig. 457, weighs 49 carats, and is valued at 40,000*l.* Some years ago, it was disposed of by lottery, and became the property of a young man who sold it at a low price. It is said to have

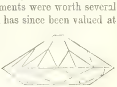

Fig. 457.

been ultimately purchased by the Pacha of Egypt for 30,000*l.*

The Austrian diamond, Fig. 158, weighs above 139½ carats. It belongs to the Emperor of Austria, and was formerly in the possession of the Grand Duke of Tuscany.

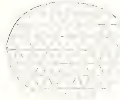
Fig. 158.

The Nassac diamond weighs 79 carats 2 grains. It was among the spoils taken during the Mahratta war, and is valued at 30,000*l.* It is of great purity, but of bad form.

The grand Russian diamond is said to have been the eye of an Indian idol, and to have been stolen from thence by a French—some say an Irish—soldier, who sold it to the captain of a ship for 2,000*l.*, and the captain disposed of it in Europe for 20,000*l.* At length it fell into the hands of a merchant, who sold it to Prince Orloff for Catherine, Empress of Russia, for 90,000*l.* in cash, an annuity of 4,000*l.*, and a patent of nobility. It weighs scarcely 200 carats.

The Koh-i-noor, or "Mountain of Light," the largest known diamond in the world, excepting the Brazilian stone among the crown jewels of Portugal, has lately been added to the trophies of the British sovereign. It was in the year 1550, before the Mogul dynasty had been established by the prowess of the great Akbar, that this marvellous stone was discovered in the mines of Golconda. It passed in the train of conquest, and as the emblem of dominion, from Golconda to Delhi, from Delhi to Mushed, from Mushed to Cabul, and from Cabul to Lahore. When first given to Shah Jehaun, it was still uncut, weighing, it is said, in the rough state, nearly 800 carats, which were reduced by the unskilfulness of the artist to 279, its present weight. It was cut by Hortenso Borgio, a Venetian, who, instead of receiving any remuneration for his labour, was fined 10,000 rupees by the enraged Mogul. It is rose-cut; and a general idea may be formed of its shape and size by conceiving it to be the pointed half of a small hen's egg; though it is said not to have risen more than half an inch from the gold setting in which it was worn by Runjeet. Its value is scarcely computable; though two millions sterling has been mentioned as a justifiable price, if calculated by the scale employed in the trade.

Small diamonds and fragments made up in small sealed bags are sold in the East by the diamond merchants. According to Jeffries, the value of diamonds is in the duplicate ratio of their weights. Thus, if an uncut diamond of one carat be worth 2*l.*, that of one cut and polished would be valued at 8*l.* sterling in the brilliant. A carat weighs four nominal grains, or 3.166 grains troy. At this rate a cut diamond of two carats would be 2 × 8 × 2 = 32*l.*; one of three, 3 × 8 × 3 = 72*l.*; one of four, 4 × 8 × 4 = 128*l.*; and one of five, 5 × 8 × 5 = 200*l.* The rose diamond is of inferior value, but has been rated at 4*l.* the carat when polished. For the purpose of estimating diamonds of inconsiderable size, the jeweller employs a gauge, in the handle of which are embedded small crystals of various relative sizes, from [illegible] to [illegible] of a carat, and a comparison is therewith made when there are numbers of various minute sizes. The rough diamond is called *bort*, and *sparks* are those small fragments which are used for glaziers' cutting diamonds.[1]

The chief application of the diamond is for ornamental jewellery, but there are other interesting applications of this gem in the useful arts. It has been employed in common with the sapphire and ruby in some descriptions of wire-drawing. Its superiority in this respect over a steel plate depends upon its superior hardness, so that a wire of invariable diameter can always be obtained. The diamond is employed as end pieces in chronometers, to close the socket in which the pivot moves, and against which it abuts. It has been successfully employed for forming small deep lenses for single microscopes, possessing high refractive power with inferior dispersive power, and very little longitudinal aberration. Mr. Pritchard has formed a very thin double convex lens of the diamond of equal radii, and about $\frac{1}{25}$ inch focus, from a very perfect stone of the first water. A diamond and a piece of plate-glass ground in a similar form, and with the same radius, are in their comparative magnifying powers as 8 : 3; so that if the power of the glass lens be 24, that of the diamond would be 64. Mr. Wilson Lowry applied the diamond instead of the steel point in etching on copper; a great improvement, as the steel point soon gives way. For these and similar useful purposes diamond bort is employed; an article of extensive application in the hands of glass-cutters and glaziers, seal-engravers, dentists, copper-plate engravers, lapidaries, clock-makers, engravers for calico-printers, hard steel turners, and engravers on that metal in every state of hardness and temper; also for dividing on hard steel and glass for micrometers, &c. Diamond powder is used in conjunction with the ordinary tools of the seal engraver, and also in other arts. No other material has been found adequate to take the place of this costly substance, unless, indeed, Mr. Nasmyth's discovery can be made available. That gentleman found that coke is possessed of one of the most remarkable properties of the diamond, in so far as it has the property of *cutting* glass; not merely scratching it, for this property is possessed by all bodies that are harder than glass. The cut produced by coke is a perfect, clear, diamond-like cut, so clean and perfect as to exhibit the most beautiful prismatic colours owing to the perfection of the incision. Coke has hitherto been considered as a soft substance from the ease with which a mass of it can be crushed and pulverised; but it will be found that the minute plate-like crystals of which a mass of coke is composed, are very hard. This discovery is likely to prove of value in many processes in the arts. Messrs. Chance of Birmingham are reported to have stated that in all probability the knowledge of this fact would lead to a saving of nearly 400*l.* a-year in their establishment alone.

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[1] The following treatises have been published on the Diamond:—*Treatise on Diamonds and Pearls*, by David Jeffries, Jeweller. London, 1751. Second Edition.—*Treatise on Diamonds and Precious Stones*, by John Mawe. London, [illegible].—*A Memoir on the Diamond*, by John Murray. London, [illegible].

The glazier's diamond has been made the subject of investigation by Dr. Wollaston, who draws a clear distinction between *scratching* and *cutting*. "In the former the surface is irregularly torn into a rough furrow; in the latter a smooth fissure or superficial crack is made, which should be continued without interruption from one end to the other of the line in which the glass is intended to be cut. The skilful workman then applies a small force solely at one extremity of this line, and the crack which he forms is led by the fissure almost with certainty to the other." Persons who set diamonds for the use of the glazier always select natural diamonds distinctly crystallized, which they term *sparks*. The reasons why those which are cut by art will not answer the purpose, is thus explained by Dr. Wollaston:—"When a diamond is formed and polished by the lapidary, all the surfaces are *plain* surfaces, as far as it is in his power to make them so, and consequently the edge or line in which they meet is straight. But in the natural diamond there is this peculiarity in those modifications of its crystals that are chosen for this purpose, that the surfaces are in general all *curved*, and consequently the meeting of any two of them presents a curvilinear edge. If the diamond be so placed, that the line of the intended cut is a tangent to this edge near to its extremity, and if the two surfaces of the diamond laterally adjacent be equally inclined to the surface of the glass, then the conditions necessary for effecting the cut are complied with. The curvature however of the edge is not considerable, and consequently the limits of inclination are very confined; for if the handle be either too much or too little elevated, then one or other extremity of the curve will be made to bear angularly upon the glass, and will plough a ragged groove by pressure of its point. But on the contrary, when the contact is duly formed, a simple fissure is effected as if by lateral pressure of the adjacent surfaces of the diamond directed equally to each side. By that means, adjacent portions at the surface of the glass are forced asunder farther than the mere elasticity of the parts beneath will allow, and a partial separation or superficial crack is produced. The effects of inequality in the lateral inclination of the faces of the diamond to the surface of the glass are different, according to the degree of inequality. If the difference be very small, the cut may still be clean; but as the fissure is then not at right angles to the surface, the subsequent fracture is found inclined accordingly. But when an attempt is made to cut with an inclination that deviates still more from the perpendicular, the glass is found superficially flawed out on that side to which the greater pressure was directed, and the cut completely fails." The depth to which the fissure made by the diamond penetrates need not be greater than $\frac{1}{200}$th of an inch. As the form of the cutting edge appeared to be the chief circumstance on which the property of cutting depends, Dr. Wollaston succeeded in giving this form to other hard stones, such as sapphire, ruby, spinell ruby, rock crystal, &c., each of which had the power of cutting glass for a short time with a clear fissure. Although the ruby is very hard, yet the edge thus produced was not durable, arising probably from "the grain or position of its laminæ having been unluckily oblique. And it seems highly probable that the singular durability of the edge of the cutting diamond is owing in some measure to this circumstance, that its hardness in the direction of the natural angle of its crystal, is greater than in any other direction, as we find to be the case in other crystals of which the various degrees of hardness in different directions can be more easily examined."[1]

Dr. Wollaston's remarks on the superior hardness of the external laminæ or skin of the diamond in its natural crystallized state are borne out by experience. Diamond-cutters are so well aware of this that they never begin to polish a diamond, however favourable the plane of a crystal may be, without abrading that plane against another diamond, in order to remove the external surface. It is this extreme degree of hardness that makes the natural diamond so peculiarly fit for cutting glass, and also for indenting extremely fine lines on the surface of glass where microscopic divisions are required.

Mr. Turrell remarks that in all cases the diamond that cuts glass most successfully has the cutting edges of the crystal placed exactly at right angles to each other, and passing exactly through a point of intersection made by the crossing of the edges. In this case it appears to be that portion of one of the edges which is very near the point of intersection that cuts, and scarcely any other. Figs. 459, 460, are an end and side elevation, and Fig. 461 a plan, of a diamond, drawn on a large scale. A B represents the leading curved part of the cutting edge, and D, Fig. 460, and C D, the line of intersection, crossing the line A B at right angles; E being the following part of the cutting edge. The general figure of the stone is indicated in all the figures by the dotted lines; and

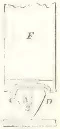

Fig. 459.

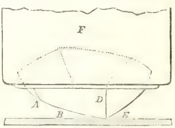

Fig. 460.

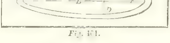

Fig. 461.

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[1] Philosophical Transactions for 1816.

its position in a hole formed in the metal block F, in which it is first adjusted and afterwards secured by hard solder, is also shown.

Fig. 462 is a side view, Fig. 463 a front view, and Fig. 464 an end view, of a glazier's diamond, mounted with a swivel adjustment for the block when connected with the handle, by means of the screw entering into a gap filed half-way through and across the metal stem. By this means the cut of the diamond is more easily obtained than when the diamond is mounted firmly into its stem; the swivel permitting the block to ply freely, and keeping the cutting edge of the diamond parallel with the edge of the straight rule, or other shaped pattern it is carried along, and thus removing the difficulty of finding its true position, and leaving the workman the task of merely attending to the proper inclination of the handle, as to whether it is carried more or less upright, or leaning to the one or the other side, to suit the cut, and which a very little practice will soon ascertain.

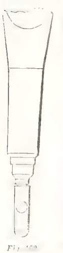

Fig. 462.

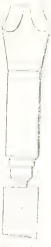

Fig. 463.

Fig. 464.

Mr. Turrell thinks that the diamond, in cutting glass, simply acts at first as a burnisher, which compresses a few particles of glass, and then immediately produces the effect of a number of infinitely small wedges, as it were, driven into the glass; the consequence being that the glass naturally separates in the direction of the line in which the diamond was carried. If minute divisions for microscopic purposes be attempted to be made upon glass with the edge of a *cut* and *polished* diamond, however perfect it may be, it instantly splinters up the surface of the glass, even with the slightest pressure, proving it to be unfit for the purpose, owing to the roughness of the edge. But with the natural diamond, the most beautiful lines are produced, and their surfaces so finely burnished, that, when ruled sufficiently close together, they will decompose light, and afford the most beautiful prismatic appearances.[1]

It must not be supposed that, because the ordinary glazier makes one diamond last him his lifetime, that the diamond does not wear out. It is usual to reset the diamond, to expose another angle when one is worn down; and in some glass-works, where enormous quantities of glass are cut up, one or two dozen diamonds are used *every week*.

The following are specimens of diamond tools. The fragments of diamonds (*diamond bort*) are fixed in annealed brass wires, by first drilling a shallow hole for the insertion of the stone, which is embedded slightly below its largest part, and the metal is pinched around it. Shell-lac is also used for cementing in these fragments, and spelter or tin solders may be fused around them with the blowpipe. A turning tool formed of a fragment or splinter of a diamond fixed in a brass wire is shown (magnified two or three times) in Fig. 465, *a*, which is the flat view, *b* being the edge view. Such a tool may be employed for turning the concave and convex surfaces of rubies and sapphires, used for the jewelled holes of chronometers, &c. Such a tool is formed of an egg-shaped diamond split in two, the circular end being used, with the flat surface upwards. With such a tool Sir John Barton engraved the surfaces of hard steel dies in lines as fine as 2,000 in the inch, arranged in hexagons, &c. The gold buttons and iris ornaments struck from these dies displayed the brilliant play of iridescent colours of the originals. By means of such an egg-shaped diamond tool, Sir John undertook to turn off from a cylindrical surface a quantity equal to the 12,000th of an inch: this he accomplished for his friend Mr. Edward Troughton. In drilling rubies, should the diamond drill be too conical, the back part is turned away with a diamond tool, to reduce it to the shape of *c*. For producing very small or very deep holes, a fine steel wire drill, *d*, is used, with diamond powder applied to the end of it. In drilling larger holes in China and glass, triangular fragments of diamond are fixed in the cleft extremity of a steel wire, as *e* and *f*. The china and glass menders also select a tolerably square stone, and mount it as shown at *g*, in the end of a taper tin tube, which wears away against the side of the hole, so as to become very thin, and by the pressure to hold the stone by the portions intermediate between its angles. A similar diamond drill, mounted in brass, has been used with the ordinary drill-bow and breastplate for drilling out the hardened steel nipple of a gun, which had been broken short off in the barrel.

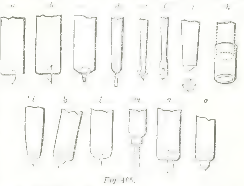

Fig. 465.

For drilling large holes, metal tubes, such as *h*, are used: they are fed with diamond powder, and grind out an annular recess, and remove a solid core.

Some of the lower figures, *l*, *m*, *o*, &c., show the conical diamond used by engravers for ruling medals and other works, and also for etching either by hand or with the assistance of machines used for ruling etching grounds. Conical diamonds are turned in a

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(1) Gill's Technological Repository, vol. i. London, 1827.

lathe by a fragment of another diamond, the outside skin or an angle being used; but the tool undergoes almost as much abrasion as the conical point.

For cutting fine lines and divisions on mathematical instruments, a splinter is used, similar to the glazier's diamond; but a fine acute edge is selected instead of the natural angle, which would be too obtuse. *k* and *l* show the side and end views of such a tool.

We shall have occasion in other articles to refer to the use of the diamond. See HOROLOGY, JEWELLING OF WATCHES, LAPIDARY-WORK, SEAL-ENGRAVING, &c

CHARCOAL is another well-known form of carbon. It is obtained in abundance by the destructive distillation of various organic products, and its appearance and properties vary with its source. If a chip of wood be ignited, the volatile matters burn away with flame, and the carbon that remains retains for some time a red glow; but if, as soon as the flame be extinguished, the chip be inserted in a narrow glass tube so as to cut off the supply of oxygen, the carbon or charcoal will cool without burning away. Charcoal may be prepared by heating to redness pieces of wood in a close vessel, or in a crucible filled up with sand, so as to protect the wood from the destructive action of the oxygen of the air. When all the volatile matters have been expelled, the charcoal remains as a black, brittle, porous mass. A very pure charcoal may be obtained by heating in close vessels sugar and some other substances which do not contain nitrogen; and by passing the vapours of certain hydrocarbons and of oils, alcohol and ether through porcelain tubes raised to a white heat, carbon is deposited in a very pure form.

Charcoal is a black, brittle, insoluble, inodorous, tasteless substance. It is a good conductor of electricity, but a bad conductor of heat. It burns with great ease in oxygen gas, but does not change by the action of air and moisture at common temperatures. When pure, it is infusible at all known temperatures. One of its most valuable properties is that of destroying the smell and taste of a variety of vegetable and animal substances, and of abstracting certain substances dissolved in fluids. Piles are charred at the end before driving, and the coat of charcoal protects them from decay; water-casks are charred on the inside to preserve the water sweet, and charcoal thrown into putrid water will take away its offensive character. Water contaminated with sulphuretted hydrogen is entirely deprived of that offensive gas if shaken up with well-burned charcoal. Charcoal deprives many solutions of colour, and hence is most extensively employed in the refining of sugar. [See SUGAR.] For this purpose the charcoal must be in a state of great porosity, minute division, and with a dull earthy aspect. Hard, brilliant charcoal, even though finely powdered, will not answer the purpose. Animal charcoal is superior to vegetable in discolouring power. Mr. Warington in attempting to decolorize ale, so as to give it the pale tint so much valued in the India market, found that the whole of the bitterness was abstracted by filtering it through animal charcoal. It was afterwards found that the salts of the vegetable alkaloids, such as sulphate of quinia, &c., are abstracted from their solutions by animal charcoal. Several inorganic salts are similarly removed.

Newly-made charcoal possesses the remarkable property of absorbing certain quantities of the different gases. In Saussure's experiments, the charcoal, having been heated to redness, was plunged under mercury, and retained there till cold: it was then introduced into the gas, and kept there for twenty-four hours, when the absorption was at its maximum. Taking the volume of charcoal as unity, the following are the volumes of gas absorbed:—

Ammoniacal gas	90
Muriatic acid gas	85
Sulphurous acid	65
Sulphuretted hydrogen . . .	55
Nitrous oxide	40
Carbonic acid	35
Bicarburetted hydrogen . .	35
Carbonic oxide	9.42
Oxygen	9.25
Nitrogen	7.5
Carburetted hydrogen . . .	5
Hydrogen	1.75

Aqueous vapour is greedily absorbed by newly made charcoal; and the absorption both of this and of the gases depends in some way upon the mechanical texture of the charcoal, and varies in different woods. Thus, it has been found that, by a week's exposure, charcoal made from—

Lignum-vitæ gained .	9.6	per cent.
Fir	13	,,
Box	14	,,
Beech	16.3	,,
Oak	16.5	,,
Mahogany	18	,,

Wood-charcoal contains about $\frac{1}{50}$th its weight of alkaline and earthy salts, which remain in the form of an ash after its combustion, but the quantity and quality of this ash vary in different trees and plants.

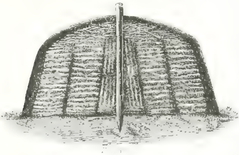
Charcoal dust has been used as a polishing-powder, and it gives a fine polish when rubbed on metals. This property does not belong to every kind of charcoal; but some years ago, Mr. J. Thomson of Glasgow, having been informed that the Dutch rush used in polishing wood owes its power to silex, supposed that wood growing on sandy soils might have the required property, and such was found to be the case. It often happens that turners meet with wood which rapidly destroys the edge of their tools. On converting some of this wood into charcoal, it was found to be well suited to copper-plate workers, &c., as a polishing charcoal-powder.

Charcoal is prepared in large quantities on the Continent, and in countries where wood is abundant and fossil coal scarce. It has been found in the manufacture of charcoal that a much greater quantity is produced when time is allowed for the oxygen and hydrogen of the wood to combine and form water.

The following table contains the results of Karsten's experiments, by which it appears that the slow process of charring is decidedly preferable to the quick. The specimens of wood employed were first dried in the air, and one hundred parts by weight of each being taken, the following figures show the respective weights per cent. of charcoal left, in the one case by the quick, and in the other by the slow, process.

	Quick Process.	Slow Process.
Young oak wood . . .	16.54	25.60
Old	15.91	25.71
Young red beech wood .	14.87	25.87
Old	14.15	26.15
Young white beech wood .	13.12	25.22
Old	13.65	26.45
Young alder wood . . .	14.45	25.65
Old	15.30	25.65
Young birch wood . . .	13.05	25.05
Old birch wood	12.20	24.70
100 years old birch, well preserved	12.15	25.10
Young deal (*P. picea*) ditto	14.25	25.25
Old	14.05	25.00
Young fir (*P. abies*) ditto	16.22	27.72
Old	15.35	24.75
Young pine wood (*P. syl.*)	15.52	26.07
Old	13.75	25.95
Lime-tree wood	13.30	24.60

Several methods are adopted on the Continent for the preparation of charcoal. One is in mounds, with a movable covering, whereby the burner is able to regulate the supply of air. A dry spot is cleared during the summer months, sheltered from the wind by a declivity or a wood, and not far from the place where the wood is felled. The ground is usually covered first with a litter of shingles, planks, or billets, and then with several inches of charcoal powder. The construction of the mound is begun at the centre, by erecting a stake as an axis, from which the mound is afterwards fired. The stake is a strong post, around which the logs are arranged concentrically; a free channel being left at the bottom, from the stake to the edge of the mound, in order that burning coals may be introduced; or three perpendicular logs are connected together with twigs, so as to leave a kind of open chimney. In either case, the ignition is always commenced from the lower part of the stakes. Partially charred wood from a former process is placed round the stake, and round this the logs, which must be nearly of the same length, and arranged one above another in the form of a ring, leaving as little space between them as possible. All the hewn logs have their sharp edges towards the stake, and the bark side outermost; all spaces occasioned by crooked wood are carefully filled up with small wood. The more slanting the logs are placed, the more loosely will they lie together, and *vice versa*; on which account the external surface of the mound is made as steep as is consistent with the durability of the outer covering. When the logs are laid horizontally, and made to radiate round the stake in one or more concentric rings, many spaces must be left, which require to be filled up, or the combustion and loss would be too great. The best mode of arrangement is to form round the stake a steep narrow mound, as a nucleus, and then to range the logs round this, in the form of a ring, pressing tightly the nucleus, so that its inclination determines that of the whole heap. As the logs are required by the forest laws to be cut of the same length, the upper horizontal logs approach nearer to each other, in proportion to the lessening diameter of the nucleus: thus the external surface forms a series of steps, which are useful in supporting the covering. The upper part of the heap is covered with fragments of wood until it assumes a rounded appearance. A mound may vary from 10 feet in diameter, and even less, up to 60 feet.



When the heap has been *levelled*, that is, all the interstices filled up with small wood, a covering is prepared with moist charcoal powder, which packs more easily and closely together than sand and earth. The first covering is a layer of turf, with the earthy side outermost; or leaves or moss may be used. The turf does not extend quite to the bottom on the edge or *foot* of the mound, but is supported a few inches above the foot by twigs, which are held by forks in the form of a ring against the heap, and are called its *armour*. The open part at the foot is left for the escape of vapour of water, which is formed at the beginning of the process. An opening in the upper part or *cap* of the mound, in the direction of the draught, would promote combustion too much. The second covering of charcoal powder or sand is put over the first, and well pressed down. The mound is then fired, by inserting red-hot coals in the channel at the foot of the mound, or at the top, so that the charred wood about the stake may be ignited as quickly as possible. The opening is then closed up, and the first period begins, namely, that in which moisture is expelled from the wood: this is called the *sweating process*. Great care is required to prevent the too rapid evolution of vapour, which would destroy the heap. During the sweating process, the smoke passes up in a yellowish grey cloud, and a portion of the vapour condenses in the covering, causing it to *sweat*, or to become quite moist. When the smoke becomes grey and lighter, the open part of the armour is covered, and the second process commences. But by this time the wood of the stake has been consumed, cavities have been formed, and the covering, by sinking in, has opened apertures for the air. The covering is quickly removed, and the wood near the stake broken up and forced together by a long pole: the empty space is filled up with fresh logs, and the covering quickly replaced and stamped down. The combustion of a small portion promotes the dry distillation of the remainder, and the charring, properly so called, begins. The mound is now left for several days, openings being made at the foot to allow the vapour of tar to escape, and to supply the necessary amount of air. The circumference of the heap now diminishes, and the mound must be watched, to see whether the diminution be uniform If not, the charring has been greater in one place than in another, and a change of direction must be given to the process, by increasing the thickness of covering in those parts, or by making holes exactly opposite to them, which conduct the draught from them to other parts. Before the process is completed, the combustion must be carried to the outside logs, by increasing the access of air, for which purpose a second series of holes is made in the middle part or *breast* of the mound, parallel with those in the foot, but fewer in number. In a short time, the thick black smoke from these middle holes changes into a thin blue cloud: the holes are then closed, and fresh ones made about two feet lower down, when the same phenomena occur. In very large heaps a third series of holes is made close to the lowest openings. If fire issues at the same time all round, the process is known to be successful. Flames are immediately extinguished by moist charcoal powder, and in those places where they do not appear, fresh holes are made, until at length the whole heap is covered up and the process at an end.

As it would require a very long time for the heap to cool, and to break it up at once would cause the charcoal to ignite, a portion of the heap is laid bare at the foot, and the logs are drawn out separately by means of a hook, and immediately quenched by being imbedded in sand or charcoal powder, or by means of water. The hole at the foot of the mound is closed up before the air has had time to produce much effect. This operation is usually performed at night, the darkness enabling the workmen to quench the charcoal more effectually than by day. The time required for charring varies from 6 to 14 days, according to the size of the mound: but with mounds of 30 feet or upwards in diameter, as much as 4 weeks are required. These mounds are very picturesque objects when seen from a distance, and especially from a height, as the Editor saw them a few years ago, in the forests of Bohemia on the borders of the Saxon Switzerland.

Another method of preparing charcoal is shown in Fig. 467. The wood is arranged in the form of a narrow lengthened wedge 20 or 30 feet long, the breadth being occupied by the blocks. The thick or hinder end is from 7 to 9 feet high, and the front or thin end only 2 feet. The heap is arranged on a gentle slope in which the foot slopes towards the back. The heap is begun by driving posts all round the quadrangular space, and within this a floor is formed of long poles placed lengthwise. The logs 8 feet in length are arranged crosswise on this floor, a space 6 inches wide for the covering being left between the posts and the sides of the logs. This space is filled up with planks and wet charcoal powder stamped in until the whole side is covered.

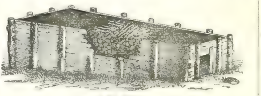


Fig. 467.

A roof is then supplied by a triple covering of twigs, leaves, and lastly, charcoal powder. On the two long sides a number of holes are made in the planks, but not in the covering, and a larger hole in front for introducing the small wood used in igniting. When all is ready, red-hot coals are inserted between the poles and the pile. When the fire has caught, which is seen by the smoke, the hole is stopped up, and other holes, 3 or 4 inches in diameter, are made in front about 15 inches from the ground. The portion of the pile between these now begins to draw whilst the upper and thicker part is sweating. When blue smoke escapes, the process is drawing to a close: the openings are then stopped and fresh ones made higher up, and so on throughout the pile. When the process has advanced to about the length of the logs, the first portions of charcoal are drawn out. It is sometimes the practice to split the logs and place them parallel with the sides of the pile, by which arrangement the carbonization is more readily diffused, and fewer openings are required.

"The process of charring wood," says Dr. Knapp, "which has been known for 2,000 years, belongs to that numerous class of inventions, in which the correct practical discernment of former times has left little to modern theory to supply, beyond the rational explanation. Simple and ingenious as the process is, it has not been modified by any essential improvement. It is impossible to imagine a spot where wood is felled, or to which it is brought by flooding or by wooden sledges, which does not offer the simple requisites for the erection of a mound; and this circumstance is of importance, as the cost of carriage upon wood so far exceeds that upon charcoal. Moreover, wood diminishes in bulk during charring as much as from 20 to 25 per cent., so that a heap comprising 3,000 cubic feet, on being charred becomes 2,250 cubic feet, and a space or hollow of 750 cubic feet would be left, into which the air having access would destroy and waste a portion of the wood. But this cavity is not actually produced, because the flexible covering yields with the wood and prevents any injury from such a cause. No arrangement could so surely and easily regulate the access of air, upon which the main point in the operation depends, as the movable covering. Each thrust of the pole is like opening a stop-cock; each shovel-full of earth like closing another. Lastly, the fire can be brought to act upon all parts of the mass of wood however extensive it may be, from the peculiar nature of the process. The object of the charcoal-burner is to char by dry distillation the great portion of the wood at the expense of the smaller portion, which in being consumed affords the requisite heat. A certain portion of the contents of the heap must be considered as necessary fuel Whilst the admitted air partially consumes one log, the adjoining one is exposed to the heat which it evolves, undergoes dry distillation, and is itself afterwards for a short time exposed to the action of atmospheric oxygen. The skill of the workmen consists in accurately observing the time when the air should be prevented having access to the wood, and the neighbouring parts are undergoing decomposition. This part of the operation is greatly facilitated by forcing the vapours, contrary to their usual course, to take a downward direction, and this retards the process, while it enables the workman clearly to discern what changes are taking place, and affords him leisure to take the necessary precautions. The fire, beginning at the middle of the heap, gradually proceeds to the circumference, and thus the nucleus of the heap, which is the first to be completely charred, is protected by an enclosure of burning wood impermeable to air, from the destructive influence of oxygen. One drawback to these positive advantages is the loss of all available secondary products, namely, tar and pyroligneous acid. The sale of these very much depends on the nature of the country, and is often exceedingly small, and yet various methods have been tried, though not always with success, for collecting them. To collect these products from the mound generally does more damage than they are worth. Some have proposed to form the covering of slaked lime, in order to preserve the acetic acid as acetate of lime: others, that it should consist of portable hurdles covered with clay, which being supplied with tubes might carry off the vapours to condensing vessels. This, however, would be depriving the cover of its most useful quality, namely, flexibility. The long masses or piles, Fig. 467, are better suited for condensing arrangements, and the best proposition is, to place a tube in the coating at the thicker end, which shall conduct the vapours to a vessel of water. When it is not necessary to change the spot for the heap, then the base may be built in the form of a flat funnel, the lowest part of which, the middle, is connected with a channel leading to a pit at the side, in which tar and pyroligneous acid may be collected."

Charcoal furnaces have been invented in order to collect these secondary products. In the furnace shown in section Fig. 468, the air has access through the bars *d*, the draught being regulated by a tightly fitting ash-pit door. The wood is put in through the opening at *a* and afterwards through *b*. When the process is complete, the charcoal is taken out through *a*. During the process these openings are bricked up, but the air is allowed to enter through the bars until the walls of the furnace have attained a heat sufficient to complete the carbonization, the doors are then completely closed, and earth is thrown against them, when thick smoky vapours of tar appear.

In Russia, Sweden, and China, carbonization is carried on in pits, the sides of which are made to form the furnace. The pit is usually situated on the side of a hill, and is in the shape of an inverted cone. At the side is a tar-vessel, which is connected with the sole of the furnace by an inclined tube. The pit is filled with finely cleft wood, and the top is then closed with a covering of earth, and holes are made in this for the draught. In some cases, air channels are made down the sides of the furnace and enter above the sole. Some further details on this subject will be given under the article TAR.[1]

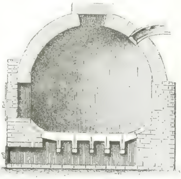


Fig. 468.

The charcoal which is left after the distillation of bone is known as *bone-black* and *ivory-black*. [See BONE.] LAMP-BLACK, another form of charcoal, is prepared in large quantities, by the manufacturers of turpentine, from the impure resin and other refuse matters that remain after the distillation of the turpentine. These are burnt in iron pots, or in a furnace, and the dense smoke arising from the combustion is introduced into cylindrical chambers, hung with sheep-skin or with sacking, upon the surface of which the soot or lamp-black is deposited. It is swept off from time to time, and sold without any further preparation. A cone of sheet-iron, Fig. 469, hangs within the cylinder: this is pierced at the top with a small hole to allow the smoke to escape, after it has deposited the greater part of its carbon, and when the operation is terminated, this cone is used as a scraper, for, by raising or lowering it, by means of the rope and pulleys, it scrapes against the skin or canvass sides of the chamber, and detaches the lamp-black. The lamp-black thus prepared is not pure charcoal, as it is mingled with resinous and bituminous substances, with salts of ammonia and other matters; but by heating it to redness in a close vessel, all these impurities are driven off, and there remains a charcoal almost pure, for it burns away with scarcely any perceptible residue.

The formation of lamp-black is easily explained.

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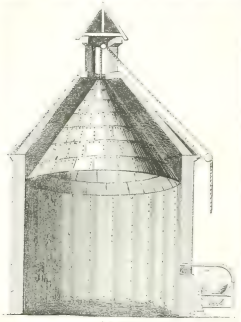
(1) These details respecting the methods of carbonization practised on the Continent, have been abridged from an excellent work by Dr. Knapp of Giessen, entitled "Chemical Technology, or Chemistry applied to the Arts and Manufactures," translated by Dr Ronalds and Dr Richardson. 2 vols. 8vo. London. 1848.

If a gaseous compound of hydrogen and carbon is brought in contact, at a high temperature, with a quantity of oxygen sufficient to combine with its



hydrogen, but not sufficient to form any compound with the carbon, it is evident that water will be formed, and carbon deposited. The resinous, oleaginous and other substances used in this manufacture are heated to a point sufficient to raise them into vapour, and then this vapour undergoes an imperfect combustion. The chief use of lamp-black is in the manufacture of printer's ink, and for this purpose it has lately been prepared by the combustion of coal-tar.

Dumas gives a description of the manufacture of a coarse kind of lamp-black from some descriptions of coal: it is used in paying ships, and for other purposes where a good colour is no object.

There are other kinds of black used in the arts, such as *Spanish black*, which is the carbon of cork, and *vine-black*, the carbon resulting from the combustion of vine tendrils: these two have a brownish tint; *peach-black*, from peach kernels: this has a bluish tint; [illegible] or *Frankfort black*, used in making the ink for copper-plate printers, is said to be produced by carbonizing a mixture of grape and wine-lees, peach kernels, and bone shavings.

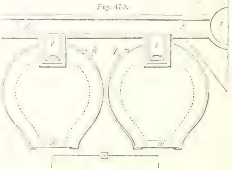
COAL-GAS CARBON. In the manufacture of gas, the first products of distillation are sometimes decomposed, and a pure variety of carbon is deposited in layers in the gas retorts. It is of a somewhat greyish colour, it breaks with an earthy fracture, and its sp. gr. is about 1.8. Steel has been made by passing coal-gas over ignited iron, contained in an air-tight iron chest.

PLUMBAGO, GRAPHITE, and BLACK-LEAD may also be considered as varieties of carbon. [See BLACK-LEAD.]

ANTHRACITE, MINERAL CHARCOAL, GLANCE-COAL, such as the *culm* of Wales and the Kilkenny coal of Ireland, are forms of carbon more or less pure: they do not readily burn, but when ignited, emit no flame or smoke, and leave but little ash.

COKE is the residual carbon of pit-coal, after the volatile matters have been expelled by heat. It has a porous texture, and a lustre sometimes approaching the metallic. It is a valuable fuel, producing an intense and steady heat, leaving very little residue after combustion. As the railway companies are not allowed to produce smoke in their locomotive engines, coke is the fuel employed therein. The small refuse coal which was formerly burnt to waste at the pit's mouth, is now profitably employed in the manufacture of coke; and so great is the demand for this article, that machines are erected for crushing the large coal into small, for the purpose of being made into coke. Small coal is coked upon vaulted hearths with very flat roofs. At the Camden Town station of the North Western Railway, a range of eighteen coke-ovens has been erected, in two lines, on a bed of concrete, the whole of which discharge their products of combustion into a horizontal flue, which terminates in a chimney-stalk, 115 feet high. Fig. 470 is a ground-plan of the ovens, each of which is 12 feet by 11 internally, and having 3 feet thickness of walls; *a a* is the mouth, $3\frac{1}{2}$ feet wide on the outside, and about $2\frac{3}{4}$ feet within; *e e* are the entrances to the flue: they may be shut more or less by horizontal slabs of fire-brick, resting on iron frames, pushed in from behind, to modify the draught of air. The grooves of these damper-slabs admit a small stream of air, to complete the combustion of the volatilized particles of soot, by which means the smoke is thoroughly consumed. The flue *ff* is $2\frac{1}{2}$ feet high, by 21 inches wide. The chimney *c*, at the level of the flue, is 11 feet internal diameter. *k k* are the keys of the iron hoops which bind the brickwork of the oven. According to Dr. Ure, "each alternate oven is charged, between 8 and 10 A.M. with $3\frac{1}{2}$ tons of good coals. A wisp of straw is thrown in on the top of the heap, which takes fire by the radiation from the dome, (which is in a state of dull ignition, from the preceding operation,) and inflames the smoke then rising from the surface by the re-action of the hot sides and bottom upon the body of the fuel. In this way, the smoke is consumed

Fig. 470.



at the very commencement of the process, when it would otherwise be most abundant. . . . As the coking of the coal advances most slowly and regularly from the top of the heap to the bottom, only one layer is affected at a time, and in succession downwards, while the surface is always covered with a stratum of red-hot cinders, ready to consume every particle of carburetted or sulphuretted hydrogen gases which may escape from below. . . . The coke being perfectly freed from all fuliginous and volatile matters, by a calcination of upwards of 40 hours, is cooled down to moderate ignition by sliding in the dampers and sliding up the doors, which had been partially closed during the latter part of the process. It is now observed to form prismatic concretions, somewhat like a columnar mass of basalt. These are loosened by iron bars, lifted out upon shovels furnished with long iron shanks, which are poised upon swing chains with hooked ends, and the lumps are thrown upon the pavement, to be extinguished by sprinkling water upon them from the rose of a watering-can; or they might be transferred into a large chest of sheet-iron, set on wheels, and then covered up. Good coals thus treated yield 80 per cent. of an excellent, compact, glistening coke, weighing about 14 cwt. per chaldron. The loss of weight in coking, in the ordinary ovens, is usually reckoned at 25 per cent.; and coal, which thus loses one-fourth in weight, gains one-fourth in bulk." [See APPENDIX.]

[illegible]

CARBONIC ACID and CARBONIC OXIDE. Carbon and oxygen possess a very powerful affinity for each other when the temperature is sufficiently raised: under ordinary circumstances, and at the usual atmospheric temperatures, they do not combine. The only binary compounds of carbon and oxygen which have been isolated are *carbonic oxide,* which is composed of 6 parts, by weight, of carbon, and 8 of oxygen, and carbonic acid, which contains 6 carbon and 16 oxygen. We will first notice carbonic acid, which is always produced when charcoal burns in contact with air or in oxygen gas: it is also produced by respiration and fermentation. It may be prepared conveniently by the action of muriatic acid on fragments of marble: carbonic acid escapes with effervescence, and chloride of calcium is left in solution.

The gas is colourless, of a pungent odour, and acidulous taste. Its sp. gr. is 1.529, and 100 cubic inches at 60°, and at a pressure of 30 inches as indicated by the barometer, weigh 47.303 grains. This gas extinguishes all burning bodies even when largely diluted with air, for a candle will not burn in a mixture of 4 volumes atmospheric air and 1 volume of carbonic acid. Nor will this gas support animal respiration, for a small portion of it in the air soon proves fatal. An animal cannot live in a mixture which extinguishes a lighted candle, and hence the old practical rule of letting a light down into a well before any one ventures to descend. If the candle burn, it is judged safe, but Dr. Christison relates cases in which a light has not been extinguished, but the men who descended instantly became insensible. When an attempt has been made to inspire pure carbonic acid, there was a violent spasm of the glottis, which prevented the gas from entering the lungs. If sufficiently diluted with air to admit of its passing the glottis, it acts as a narcotic poison. Many persons have lost their lives either intentionally or by accident by sleeping in a confined room with a pan of burning charcoal. Carbonic acid is quite incombustible, and this gas consists of carbon in its highest degree of oxidation.

When lime-water comes in contact with this gas it becomes turbid. The lime unites with the gas, forming carbonate of lime, which being insoluble in water renders the solution of lime-water milky.

Recently boiled water absorbs its own volume of carbonic acid at 60° and 30 inches pressure; but it will take up much more if the pressure be increased. The quantity absorbed is in exact ratio with the compressing force, the water dissolving twice its volume when the pressure is doubled, and three times its volume when the pressure is trebled. On removing the pressure the greater part of the gas escapes, and produces that effervescence which we see when a bottle of ginger-beer, soda-water, cider, or brisk champagne is opened. Water saturated with carbonic acid sparkles when it is poured from one vessel to another. The solution has a pleasant acid taste, reddens litmus paper, but the blue colour returns as the gas escapes. Lime-water is at first rendered turbid by the solution, but it soon becomes clear, as carbonate of lime is soluble in excess of carbonic acid. The agreeable pungency of malt liquors is in great measure due to the presence of carbonic acid, the loss of which by exposure to the air causes them to become stale. Spring and well-water contain carbonic acid absorbed from the air, and to which they partly owe their pleasant flavour. The insipid taste of water that has been boiled is from an absence of carbonic acid. This gas is always present in the atmosphere, even at the height of several thousand feet. Its presence may be proved by exposing lime-water to the air. A pellicle of carbonate of lime soon forms on its surface. The sources of carbonic acid in the air are numerous. It is an abundant product of combustion, of respiration of animals, which is in fact only a kind of slow combustion, and it is generated by fermentation, and in all those changes which take place in dead animal and vegetable matter. When these processes take place in low and confined situations, the poisonous carbonic acid, or *choke-damp* as it is sometimes called, may accumulate and prove fatal to animal life. But in general this gas is equally diffused throughout the air, and never accumulates unless there is some local source of supply; for although so much heavier than the atmospheric air, the strong diffusive tendency of gases prevents it from separating from the lighter gases of the air. By its equal diffusion it ministers food to growing plants, which decompose the carbonic acid, retain the carbon, and give out an equal volume of pure oxygen in return. Many mineral springs also contain carbonic acid, and in combination with lime it forms extensive masses of rock in all countries. Carbonic acid unites with alkaline substances, forming salts which are termed *carbonates*.

Carbonic acid has been obtained in a liquid, and also in a solid form, the first example of a solidified gas. The liquefaction of carbonic acid was effected by Faraday in the following manner:—A strong tube, Fig. 472, about $\frac{1}{4}$ inch diameter and 8 inches long, being bent at about 2 inches from its end to an obtuse angle, and sealed at the shorter end, sulphuric acid was poured in through a small funnel, so as not to soil the larger leg, which was then loosely filled with fragments of carbonate of ammonia, and also hermetically sealed. The acid was then made to run upon the salt, and the evolved carbonic acid gradually appeared condensed by the mutual pressure of its particles into a liquid form. Many precautions are necessary to guard against explosion; the face and eyes must be protected by a strong mask with goggles for the eyes, and the hands must be shielded by thick gloves. Great care is required in handling the tubes, for in some cases, after having held the fluid safely for weeks together, they have exploded from some slight increase of temperature. It appears from some experiments by Mr. Addams, that the elastic force of liquid carbonic acid at different temperatures is as follows:—

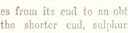
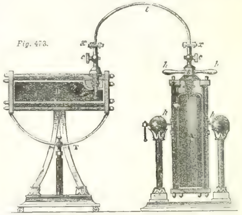


Fig. 472.

Temperature.	Pressure in pounds per square inch.	Atmospheres of 15 lbs. each.
0°	280	18.1
10	300	20
30	398	26.5
32	413	27.6
50	520	31.7
100	935	62.3
150	1,496	99.7

Liquid carbonic acid has been obtained in very large quantities by an apparatus, contrived by M. Thilorier, the principle of which is identical with that of Dr. Faraday's glass tube. The liquid carbonic acid is first produced in a *generator*, from which it is distilled into a *receiver* for the purpose of separating it from the sulphate of soda, &c. The products of several successive operations are collected in this receiver. The generator, A Fig. 473, is a cylindrical chamber of lead enclosed within a copper cylinder, and strengthened by wrought-iron rings. The top and bottom are further strengthened by thick iron plates. The generator is supported on an axis at *p p*. The construction of the receiver B is similar to that of the generator. The opening at *o* in the generator is closed by a screw-plug *s*, pierced in the direction of its axis, and furnished with a stop-cock *c*. The screw-plug is moved by a double handle *h h*. A ring of lead compressed into the double throat between the neck of the generator and the screw-plug, renders the vessel perfectly tight. The receiver B has an opening which is furnished with a copper tube *a*, passing nearly to the bottom of the vessel, and is furnished with a stop-cock *c* on the outside. Communication is established between the two vessels A and B, by means of a copper tube *x t x*.

Fig. 473.



For the production of the liquid carbonic acid, the following is the charge for a generator 2 feet long, and 4 inches internal diameter:—6.25 lbs. of water at 100°: 2.75 lbs. of bicarbonate of soda in fine powder, and 1.47 lbs. of sulphuric acid of full commercial strength. These proportions leave an excess of alkaline salt, which is desirable in order completely to neutralize the acid. The generator is charged by taking out the valve-plug and introducing some of the tepid water by means of a funnel: the carbonate is then added, then the remaining water, and the whole is stirred up with a rod. The acid is introduced separately in a copper tube, Fig. 474, in order to prevent it from acting upon the materials before the screw-plug is replaced. This being done, the generator is inclined, when the acid flows out of the tube and mingles with the alkaline solution, and in order to mix them more completely, the vessel is turned over and over several times upon its axis *p p*. The generator is then allowed to stand a few minutes erect with its

Fig. 474.

valve end upwards, and the liquefied carbonic acid being lighter than the resulting sulphate of soda, rises and floats upon it. The generator is then connected with the receiver by means of the tube *x t x*, as in Fig. 473, and the valves of both vessels being opened, the carbonic acid passes from A into B. The receiver should be surrounded by cold or iced water, while the generator is allowed to retain its heat. The valves are then closed, the contents of the generator discharged, and the operation is repeated. When the receiver is properly charged, it contains liquid carbonic acid with a quantity of highly condensed gas above it. Upon opening the stop-cock the expansion of the gas forces the liquid up the tube *a c*: a portion of it immediately passes into the state of gas at the orifice, and another portion is frozen into a white snow-like solid, in consequence of the large quantity of heat rendered latent in the passage of the liquid acid into the gaseous state. The solid carbonic acid is blown out in finely divided particles, but it may be collected in a [illegible] *box*, Figs. 475, 476. This consists of two parts *a b c d*, *a' b' c' d*, which admit of being readily separated and put together again, by one end sliding a little within the other, and held together by two obliquely grooved holders placed on opposite sides of the joint. The lower part *a b c d* has at the side a small tube *t*, which is screwed to the tube *a c* of the receiver, Fig. 473. On opening the stop-cock *c*, a jet of liquid carbonic acid enters the box and strikes upon a small tongue *m*, arranged so as to produce a gyratory motion; the portion of the liquid which becomes transformed into gas, escapes by the central tubulures *c d*, *c' d'*, while the remainder solidifies within the box.

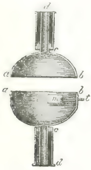


Fig. 475.

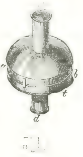


Fig. 476.

Mr. Addams has simplified and improved the apparatus for the liquefaction and solidification of carbonic acid gas. The improved apparatus is described in the last edition of Professor Brande's Manual of Chemistry.

Liquid carbonic acid is limpid, colourless and very fluid. Its sp. gr. at 32° is 0.83, and it distils readily and rapidly at the difference of temperature between 32° and 0°. Between 32° and 86° Fahr. the liquid increases in bulk from 20 to 29, which is four times greater than the dilatability of air within the same range. It is insoluble in water and in the fat oils, but it is soluble in alcohol, ether, turpentine, and sulphuret of carbon. Its refractive power is much less than that of water. Some years ago Mr. Brunel attempted to make use of this liquid as a motive power, and the machine which he proposed to construct, to be moved by the expansive force of this gas, was exhibited in diagrams, &c. at the Royal Institution. This machine, however, seems to have failed, for the same reason, as it appears to us, that caused M. Thilorier's apparatus to succeed; namely, by allowing the liquid to escape and assume the gaseous form, so great a degree of cold is produced that a portion only expands into gas, and can be applied as a prime mover, while the remaining portion freezes into a solid. If this really be the explanation of the failure of this machine, and it had been understood at the time, M. Thilorier's beautiful discovery would have been anticipated by twenty years. Solid carbonic acid when first produced, is in the form of a white flocculent powder: it can be melted and resolidified, when it appears clear and crystalline like ice. It melts at −70° or −72° Fahr., and the solid is heavier than the fluid. "At this temperature it has a pressure of about 5.33 atmospheres. It is remarkable for the high tension of the vapour which it gives off whilst in the solid state: there is no other substance which at all comes near it in this respect, and it causes an inversion of what in all other cases is the natural order of events: thus, if, as in the case with water, ether, mercury or any other fluid, that temperature at which carbonic acid gives off vapour equal in elastic force to one atmosphere be called its boiling point; or if (to produce the actual effect of ebullition) the carbonic acid be plunged below the surface of alcohol or ether, then we shall perceive that the freezing and boiling points are inverted; that is, that the freezing point is the hotter, and the boiling point the colder of the two, the latter being about 50° below the former. (*Faraday*.) In the solid state it moves about upon any polished surface, like a drop of water upon white-hot iron, and slowly disappears. Addams found the surfaces from which it had evaporated, in a negatively electrical state. In its usual state the flocculent acid feels like snow, and owing to its low conducting power, it does not evaporate very rapidly, nor feel extremely cold, though its actual temperature is lower than 100° below the zero of Fahrenheit. When a little mercury is put into a saucer and covered by solid carbonic acid, the addition of a few drops of good ether forms a semi-fluid mass, by the contact of which the mercury is immediately frozen: in this way ten pounds of mercury may be frozen in less than eight minutes. In further illustration of the extraordinary relations of this substance, a large lump of the solid carbonic acid was kept for a minute in a red-hot crucible, and afterwards a pound of mercury was frozen with it. When a piece of the solid acid is put into a gas-bottle, it gradually becomes gas, which may be collected as usual over water; or its conversion into the gaseous state may be more strikingly observed, by letting up a small piece of it into an inverted jar of water." (1)

The temperature of the mixture of solid carbonic acid and ether in the air, as measured by a spirit thermometer, was found by Faraday to be −106° Fahr., but when this mixture was placed beneath the receiver of an air-pump, and exhaustion rapidly made, the temperature sank to −166° Fahr. In 1845 Dr. Faraday took advantage of this low temperature to resume his experiments on the liquefaction of the permanent gases, which had been undertaken by him with such happy results 22 years before. By using narrow green glass tubes of great strength, powerful condensing syringes, and the low temperature obtained as just described, several of the compound gases were liquefied and even frozen into colourless transparent solids: alcohol did not freeze, but it became thick and oily; while oxygen, hydrogen, nitrogen, nitric oxide, carbonic oxide, and coal gas, could not be liquefied at −166° Fahr. while subjected to pressures varying from 27 to 58 atmospheres.

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(1) Brande: Manual of Chemistry, 1848.

Carbonic oxide may be obtained from carbonic acid, by subjecting that gas to the action of substances which abstract a portion of its oxygen; as for example, by passing carbonic acid over red-hot charcoal or metallic iron, one half of its oxygen is removed. There are various other methods of obtaining this gas known to the chemist. Carbonic oxide differs essentially in its properties from carbonic acid. It is combustible, burning with a beautiful pale blue flame, producing carbonic acid as the result of combustion. It is colourless, has very little odour, but is very poisonous. It explodes when mixed with oxygen and fired by the electric spark. Its sp. gr. is .973, and 100 cubic inches weigh 30.21 grains.

Carbonic oxide is sometimes produced from the carbonic acid which results from the combustion of coal in our furnaces, and the cause of this is clearly stated in the following extract from an admirable lecture by Professor Miller of King's College.[1] He is tracing the progress of the combustion of a pound of pure carbon.

"When this pound of pure charcoal is burned, when it combines with oxygen from the air, it gives out a certain amount of heat, which, from careful experiment, appears to be sufficient to convert thirteen pounds of water at 60°, the ordinary temperature of the air, into steam at 212°, the boiling-point of water. In other words, it will boil away thirteen pounds of water; and more than the heat sufficient to effect this, no ingenuity can make it furnish. It is evident, however, if it is capable of furnishing this quantity of steam, that unless we actually generate this full amount in our steam boilers,—unless the whole thirteen pounds of water is turned into steam for every pound of charcoal which we consume, that we are incurring a loss greater or less in proportion to the quantity of steam produced. Some waste is almost inevitable; but our exertions cannot be considered to be crowned with the success which is attainable so long as any considerable loss is sustained; we must therefore examine and reflect upon the various circumstances which may produce such loss. The first and most obvious loss arises from the escape of the heated air from the chimney before it has surrendered to the boiler the full amount of heat which it is capable of relinquishing. It is manifest, that the best method of obviating this consists in so arranging the chimney and passages for the products of combustion, that they shall circulate thoroughly around the boiler, and that sufficient time may be allowed for them to part with their high temperature before escaping into the external air. Doubtless this is an extremely difficult thing to effect to the best advantage, and is the part where some loss is inevitable; but it is so striking a point that I need not here dwell longer upon it. Another important source of loss is the cooling down of the pipes and boiler after the steam has been generated, but before it has been used. And here science has rendered most important service; in the Cornish engines especially this point has received attention,—and four times the quantity of work may now be obtained with the same expenditure of fuel from an engine which Mr. Watt considered was doing the full amount of work that could be expected from it. There is, however, another very important but more unsuspected mode in which loss is sustained, and one which is intimately connected with the chemistry of combustion. It depends upon an insufficient supply of air. It is a fact, not less singular than important, that charcoal, or coke, may be dissipated in vapour, and may apparently be wholly consumed, by one half of the amount of air that is usually required in an open fire, under circumstances where the full quantity of heat is given out; and it is to be observed, that in this case one pound of charcoal instead of emitting heat enough to convert thirteen pounds of water into steam, will only give out one-fifth of the heat, and will therefore raise but little more than two pounds and a half of water into steam. This important fact depends upon the property which charcoal has of forming two compounds with oxygen; in the first case where the most heat is emitted, twice the amount of oxygen is taken up, and carbonic acid gas, or fixed air, is produced; in the second case, a gas is obtained also, called carbonic oxide; it is colourless, and therefore escapes notice; but it is combustible, which carbonic acid is not, and in burning, it gives out a large amount of heat; in short, the other four-fifths of the heat which are deficient when charcoal is burned into this gas.

"Now, the way in which this gas is produced is worthy of notice. It is not formed, in the first instance, by the direct union of the coke or charcoal with the oxygen of the air; for carbonic acid is the compound which is invariably obtained; but when this carbonic acid is made to pass over red-hot coals, it dissolves a portion of the coal, becomes dilated to twice the bulk it occupied, and actually, instead of increasing the heat of the furnace by the quantity of coal with which it thus unites, it most materially diminishes it, and carries it off in sheer waste

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(1) An Introductory Address to the Medical Classes of King's College, delivered October 1, 1845; with an Inaugural Lecture at King's College, given October 6, 1845. By W. A. Miller, M. D F.R.S. Professor of Chemistry, King's College, London 1845.

I can show you this combination of the incombustible carbonic acid with the combustible coal, and the production of a gas which is capable of taking fire on the application of a light, by passing the carbonic acid through a long glass tube filled with charcoal, and heated to redness by passing it across the furnace, and then collecting in separate vessels the gas which escapes from the apparatus. Now let us consider what is actually going on in many of our furnaces: these are usually open to the air at bottom by the bars of the fire-grate,—brisk combustion takes place, and the body of coke above becomes of a bright red heat; but the air is quickly deprived of its oxygen by the lowest layer of coal, the draught carries up the exhausted air, and with it the carbonic acid that has been formed; this gas, as it passes over the intensely ignited coal, dissolves a fresh portion, cools the fire and ascends the chimney; when it reaches the top of the chimney, it has become too much cooled down to take fire as it comes into the air, and passes off unsuspected and to waste; actually carrying with it four-fifths of the heat that it ought to give out if the coal that it takes off had been burned with a due supply of air. I do not mean to say that the whole of the carbonic acid is ever entirely converted into carbonic oxide; the gas is not in contact with the heated coal for a sufficient length of time to produce this effect; but this I do say, that in all furnaces of the common construction, a large loss is sustained in this insidious and unsuspected manner.

"In the case where coal and not coke is employed, still greater loss is sustained; all the visible smoke is wasted, a good deal of carbonic oxide in addition passes off in the invisible form, and still more coal gas escapes unnoticed; the coal in the upper part of the furnace becomes coked by the heat of the lower portion, and nearly all that the gas-works obtain by distillation of coal in retorts, here passes unheeded into the air. The question, therefore, of the consumption of smoke, resolves itself not merely into a question of health and public convenience, to which too often a deaf ear is turned by those who are deriving profit at the expense of the sufferers, but it is actually a question of economy on the widest scale—it is a question on which common sense and common humanity are alike agreed,—and it is therefore a point which eventually will demand from self-interest, that attention which mere good feeling would long solicit in vain."

CARBURETS. Carbon unites with only a few of the metals forming *carburets*, or *carbides*. The only carbides of importance are those of IRON, manganese, palladium, iridium, and a few other metals also combine with carbon.

CARBURETTED HYDROGEN, see GAS.

CARDBOARD. The manufacture of the cardboard which is used for playing cards and for address cards, contains a number of interesting processes, which we will describe in the order in which we recently witnessed them at the house of Messrs. Sabine, Poppin's Court, Fleet Street.

Cardboard consists of a number of thicknesses of paper pasted together, pressed and polished on the two surfaces. Ordinary cardboard consists of two sheets of white paper with a sheet of cartridge paper between them, and the thickness of the board is determined by the stoutness of the paper. For stout cards two or more sheets of cartridge paper are interposed. *Bristol-board*, which is used in sketching, is formed of two or more thicknesses of white paper only. Hence cardboards are known as *three-sheet*, *four*, *six*, or *eight-sheet* boards, either *white* or *coloured*. The outer surfaces may be white, blue, green, lavender, or pink, &c., the colours being produced by two outer surfaces of coloured paper. *Enamelled* cards are produced by a process which will be described presently.

For the sake of simplicity we will confine our attention to the manufacture of three-sheet board. The arranging of the paper for this is called *mingling*. That is, a ream of white demy paper is spread open, and between every two sheets, one sheet of cartridge paper is placed; and the pile when complete is called a *head*, consisting, of course, of a ream and a half of paper.

The next process is *pasting*. A man stands at a bench with a mahogany slab before him, the head of paper on his left hand, and a large tub of paste on his right. The paste-brush resembles the broom part of a long handled hair broom. The operations are conducted as follows:—Pulling the first sheet from the head upon the mahogany slab with his left hand, the paster with his large brush saturated with thin smooth paste covers it with a layer by two or three skilful movements of the hand and arm. He then pulls down upon this pasted surface a sheet of cartridge paper, the top surface of which is in like manner pasted. He next pulls down upon the pasted cartridge surface *two* sheets of white paper, and covers the upper surface only with paste. One sheet of cartridge paper is pulled down upon this and pasted; then two sheets of white paper, and so on until the whole head has been pasted. Now it is obvious that by pulling down two sheets of white paper

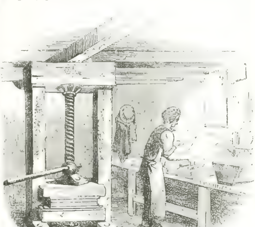

Fig 477. PASTING AND PRESSING.

upon a pasted surface, and then covering the upper surface of these two sheets with paste, two contiguous surfaces will be left unpasted, and these form the boundary between every two sheets of cardboard. One man will paste 4 heads of paper, or 7 gross of cardboards, in one day. This will consume about 14 lbs. or 16 lbs. of flour, reckoning 1 lb. of flour equal to 1 gallon of paste. It is not usual to damp the paper previously to pasting, unless papers are brought together which will not *marry*, as in the case of a hard hand-made paper, and a softer and more equable machine-made paper. In such a case the paper must be previously damped in order that the pasted surfaces may properly unite.

When the head has been pasted, it is put into an upright press, and condensed by the action of a well-oiled iron screw, and a long iron lever worked by two men. The water of the paste oozes out at the edges of the head, and falling into a channel in the lower bed of the press, escapes through a hole into a bucket, which becomes entirely filled with clear water from the produce of one man's work in the course of one day.

The next process is *drying*. Every evening before the men leave off work, each man takes out of the press the heads which he has pasted during the day, and placing one of the short sides of the heap before him, he pierces the boards close to the edge with a couple of holes. Then taking up two of the cardboards, he passes a piece of soft copper wire, about $1\frac{1}{2}$ inch long, furnished with a little square of cardboard at one extremity, into each hole. In this way he goes on piercing and threading until the four heads are thus prepared. They are then taken to the drying-rooms, where a number of lines are stretched across near the ceiling, and bending the copper wires into the form of a hook, the boards are thus hung in pairs on the lines to dry. The room is heated artificially, and in the course of twenty-four hours, that is, on the next evening when the lines are wanted for the next day's work, the boards are sufficiently dry. On giving every pair a pull, the soft copper wire straightens, and releases them from the line. They are then separately brushed with a hair brush to remove any dust, &c.

The boards are now rough on the surface, warped and uneven. They are made smooth and even by passing them between a couple of powerful iron rollers in contact with thin sheets of smooth copper plate. The rollers very much resemble those used in bookbinding, [See BOOKBINDING, Fig. 166, p. 155,] and in order that the cardboards may be passed through the rollers square or without overlapping each other, they are placed in a three-sided frame very much like a small dinner tray with the front side left out. A cardboard is first placed in this frame, and upon it a sheet of copper, not quite so large as the board, then another cardboard, then a second sheet of copper, and so on alternately until about a dozen cardboards and as many sheets of copper have been piled up. The bottom roller is furnished with a handle and a fly wheel. The upper roller is movable upon a horizontal axis. A boy is kept turning the handle, and a man takes the pile from the frame and passes it between the rollers, and as soon as it gets within their grip, the resistance is too great for the boy to overcome. The man therefore takes hold of one of the radii of the fly wheel, and pulls it round; the pile passes through, and is received by a boy on the other side; who passes it over the top roller, and the man sends it a second time, and in some cases a third and a fourth time through the rollers. The effect of this rolling is very remarkable. The rough uneven cardboard is converted into a perfectly even board with a beautifully polished glazed surface. Each surface has in fact taken an impression of the smooth, hard, rigid surface of the copper plates, a species of *surface printing*, as simple in its operation as it is successful in its results. The rollers and copper plates are cold, but after passing through the rollers two or three times, the cardboards become sensibly warm to the touch in consequence of the enormous compression to which they have been subjected. While the rolling is going on, two boys are preparing another pile, and when one pile has been rolled, another boy takes out the sheets of copper and arranges the cardboards in a heap.

The cards are now ready for the *sianciller* if they are to be formed into playing cards, or for cutting up into sizes if for address cards. For the latter purpose there are various sizes known in the trade, such as *ladies' size*, *gentleman's size*, *trade-card size*, &c. The *large size* card is a parallelogram measuring 4 inches by 3 inches; *one-third large* or *gentleman's size*, is 3 in. by $1\frac{1}{2}$ in.; *ladies' size* is $2\frac{3}{8}$ in. by $3\frac{3}{8}$ in. Then we have *large thirds*, 3 in. by $1\frac{3}{4}$ in.; *outsides*, also called *Cobourg*, *Town size* or *thirds*, *extra broad thirds*, *reduced half large*, all referring to a card which measures 3 in. by 2 in. Then there is *half large*, 3 in. by $2\frac{1}{4}$ in.

The cardboards are first cut into lengths or long strips 4 inches or 3 inches wide, according to the size required. These strips are then cut up with wonderful celerity into cards of one or other of the above dimensions. The cutting is performed by means of an apparatus very similar to the board-cutting machine described under BOOKBINDING, (Fig. 172, p. 157.) The cards are lastly tied up in packets ready for the copper-plate printer.

The enamelled surface of address cards is produced by means of a very pure variety of white lead, known as *China white*, *Krems*, or *Kremnitz white*, and *Silver white*. [See LEAD.] It is imported into this country in cakes or lumps made up in sealed packets. This substance is stirred up with pure water containing fine sise, made from parchment cuttings boiled down, and rubbed through a sieve by the hand (a most dangerous practice), in order to reduce it to a state of minute mechanical division, and to separate any gritty particles. This mixture is brushed in a thin layer over one surface of the cardboards by means of a large *flat* and closely-set brush, and it is smoothed off by a circular brush made of badgers' hair, which leaves the enamel colour free from streaks or marks. The cardboards are then placed upon a rack to dry, and in the course of an hour or two, when all trace of moisture has disappeared, the dead white surface produced by the white lead is wrought into a glossy enamel by a very remarkable process. A piece of flannel dipped into the powder of talc (a silicate of magnesia) is rubbed lightly over the surface of the cardboard, the object apparently being to supply every portion thereof with a polishing material. If the flannel were rubbed with much pressure, the already dead white surface would remain so; but when the powder is once applied a strong pressure may be used, and this is given by means of a close-set brush similar to a scrubbing brush, the continued rubbing of which produces the well-known glossy enamelled surface. The great objection to this kind of card is its liability to turn black, the sulphur of the person or of the atmosphere, which is always present in minute quantities in the form of sulphuretted hydrogen, combining with the lead, and forming a sulphuret of that metal, the colour of which is black. On holding one of these cards in the flame of a candle metallic lead is produced in small beads.

Playing-cards are produced by the ancient art of *stencilling*, an art older, in Europe at least, than printing.[1] A stencil is a thin sheet of pasteboard, parchment, or metal, in which the outlines and general forms of the figures are cut out, for the purpose of being stencilled on cardboard or paper. By passing a brush charged with colour over the stencil, the colour enters into the *cut-out* lines, and imparts the figure to the material beneath. The *pips*, or common cards, require only one colour, either black or red; but the *têtes*, or court cards, require many colours. For the production of the former, a thin sheet of cardboard is divided into a number of spaces or parallelograms equal to the size of the playing-cards, and within the first of these spaces, exactly in the centre, the form of an ace, say of diamonds, is cut out; in the second space, a diamond is cut out, near the top and bottom; in the third space three diamonds, and so on up to the ten of diamonds. The stenciller places this stencil-plate upon one of the white cardboards, rolled and polished as above described, and holding it steady with his fingers, rubs in the colour with a large, heavy, circular brush, with closely set bristles. A little of the colour, vermilion ground up with sise, is placed upon a board covered with parchment, and upon this the brush is worked until properly charged, and then it is worked upon the stencil with a rotatory dabbing sort of motion, until the forms are properly painted upon the card. For the court cards, several stencil-plates are used, one for each colour. Suppose the ground colour to be red. This goes over the cuffs, and belt, and coronet, and breeches of the knave; a stencil is then applied, which covers all the parts of the card except those which are to be painted yellow: in this stencil, therefore, the cut-out parts fall on the figure exactly where the yellow is to be produced, and this represents the gold lace, the jacket, &c.; a stencil is then applied, to allow of the application of the light brown which serves for the flesh colour; then another stencil for the dark brown that colours the hair: then there is a stencil for applying the light blue which forms orders of courtly dignities, baldrics, and shoe-strings. In this way the cardboards being covered with sets of cards, they are cut up in the same way as the address cards, and with such celerity, that a skilful workman can in two hours and a half cut up 200 packs, of 52 each, or 10,400 cards.

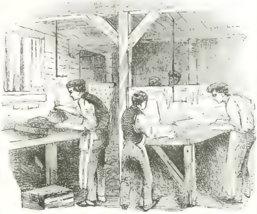

FIG. 17. STENCILLING AND CUTTING.

When the backs of the cards are ornamented with spots or small flowers, &c., these are printed in sheets from a stereotype plate, at a common hand-press, and the sheets are attached to the back of the card in the process of pasting.

The duty card, the ace of spades, is printed at the stamp-office, on sheets of thin paper, and supplied to the card-maker as he wants them. Each maker has his own plate, which is engraved at his expense by the Government authorities, and kept by them: he never being allowed even to see it. Each sheet containing aces is of course pasted to other sheets of paper, to make up the proper thickness. It forms the stamp of every pack of cards, and costs the purchaser one shilling. In cards for exportation, a

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(1) Mr. Chatto, in his ingenious and entertaining work on the "Origin and History of Playing-cards," (London, 1848,) says that in the oldest cards which he has had an opportunity of examining, and which appear to be of as early a date as the year 1440, the figures were evidently executed by means of a stencil. From the circumstance of so many women occurring as card painters in the town books of Nuremberg, between 1433 and 1477, it seems probable that they were not wood-engravers, but stencillers. Mr. Chatto thus sums up the history of playing-cards:—"Admitting cards to be of Eastern invention—a fact which appears to be sufficiently established by the evidence adduced in the first chapter—it would seem that they first became known in Europe as a popular game between 1350 and 1390. Covelluzzo, an Italian chronicler of the fifteenth century, says that the game was first brought into Viterbo in 1379; in 1393, three packs of cards were painted by Jacquemin Gringonneur for the amusement of Charles VI. of France; in 1397, the working people of Paris were forbid to play at cards on working days; and in the same year card-playing was prohibited by the magistrates of Ulm. Such are the principal facts relative to the introduction of cards into Europe. The game appears to have rapidly spread amongst all classes of people. The manufacture of cards was a regular business in Germany and Italy, prior to 1425; the importation of foreign cards into England was prohibited by Act of Parliament in 1463; and about 1484, cards, as at present, was a common Christmas game."

drawback of the whole duty is allowed; in which case, the Stamp Office furnishes a different ace of spades, which is not allowed to be used in Great Britain and Ireland. The duty from cards and dice in 1860 was £15,255.

It does not appear, from the statements made to us by Mr. Sabine, that card-playing is on the decline. The export trade to the colonies is very large. Mr. Sabine frequently sends 500 dozen packs to one place, and there are other makers in the metropolis whose trade is equally large.

Cards are also produced by printing as well as by stencilling. In 1832, Mr. de la Rue took out a patent for improvements in manufacturing and ornamenting playing-cards; and since that date, other improvements have been introduced, some of which have been made the subject of patents. The following is a brief outline of the process as at present adopted:—

The polish which is communicated to ordinary paper by pressure merely is not sufficient to produce cards of the finest quality. The high finish which is afterwards imparted is produced by a previous preparation of white enamel mixed with size. For printing the pips, sets of blocks are prepared, each containing 40 engravings of one card; and as the ordinary method of letter-press printing is used, 40 impressions of one card are obtained at the same moment. As the pips are either black or red, they are worked at the hand-press, or at one of Cowper's steam printing-machines. The têtes, however, contain five colours, including the outline, viz. dark blue, light blue, black, red, and yellow. These colours are printed separately from a series of blocks, which, if united, would form the intended figure complete: so that, by printing successively from these blocks, the colours fall into their proper places, each colour being made to *register* by means of points in the tympan of the press, or on the engraving.

The printing being completed, the sheets are left during three or four days in a room heated to about 80°, in order to fix the colours. It is of great importance to use such an ink as will not be liable to smear by repeated handling. The colours employed are prepared from the best French lamp-black, for the black, and Chinese vermilion, for the red. These are ground in oil by a machine consisting of cylinders revolving at regulated velocities.

The paper intended for the backs is tinted of the required colour, and printed in various devices by the hand-press or the steam-machine. The *plaid* or *tartan* backs are produced from a block engraved with straight lines, and printed in one colour, which is afterwards crossed with the same or any other colour by again placing the sheet on the block, so that the 2 sets of lines may cross at any required angle. Various other devices are produced by printing with blocks containing various patterns. In printing *gold backs*, size is used instead of ink: the face of the card is then powdered over with bronze-dust, and rubbed with a soft cotton dabber, by which the bronze is made to adhere to those parts only which have received the sise. The backs are also printed from wire woven into a variety of beautiful patterns: the wire is fastened at the ends by 2 pieces of wood, and stretched over a cast-iron block, to which it is fixed by screws. The printing is then conducted in the usual manner.

The pasting is performed after the printing. The printed sheets are either of double or single foolscap, and the cardboards are made 4 sheets thick; *i.e.* the front and the back, with 2 interior sheets of inferior quality. The paste is made as usual from flour and water, heated in a forty-gallon copper to the boiling-point by means of a steam-jacket: this prevents the paste from burning and acquiring a bad colour.

When the pasting is complete, a hydraulic press, of 100 tons, worked by a steam-engine, is used, to express the water from the paste. The cardboards are then hung up to dry, after which they are subjected to the pressure and friction of a brush-cylinder, in which the bristles are short and thick-set: these not only polish the surface, but penetrate into the interior. The best cards are waterproofed on the back at this stage with a varnish, to prevent them from being marked with the fingers in using. Such cards will bear washing without injury. The polishing is completed by passing the cardboards between rollers, one of iron and the other of paper, [see CALENDERING,] the former being kept moderately warm: they are then passed between 2 bright iron rollers, then milled between sheets of copper, as already described, and lastly flattened, by the pressure of a hydrostatic press of 800 tons. It has been found by experience that the beautiful polish, and perfect smoothness and flatness of these superior cards, can only be produced by a succession of processes, slow in action, and gradually increasing in power. Each cardboard is cut up as before described, first into 8 narrow slips, called *traverses*, each containing 5 cards: these are then cut up into single cards, to the amount of 30,000 daily. The cards, being properly sorted, are made up into packs, for which purpose a number of cards of the same name (probably 200) are arranged on a long table: these are then covered with other cards, and the process is repeated 52 times, with different cards, until the 200 packs are complete. They are then folded up in paper, and tied up. The best cards are known as *Moguls;* others are called *Harrys* and *Highlanders*.

CARDING, see WOOL.

CARDING-ENGINE and CARD-MAKING MACHINE, see COTTON, and APPENDIX.

CARMINE. A beautiful pigment prepared from cochineal. It was discovered accidentally by a Franciscan monk at Pisa, who having formed an extract of cochineal with salt of tartar for the purpose of employing it as a medicine, obtained a fine red precipitate on the addition of an acid. Homberg, in 1656, published a method for preparing it. As the use of this substance in reviving the roses on the cheek of beauty, and concealing the attacks of time, became known, the costly pigment became much in request. The makers of it in some of the principal towns of Europe, succeeded in preparing different varieties of it of greater or less purity and lustre. Many of these processes, even to the present day, are kept secret; and although the chemistry of the art is well understood, yet there are certain details of manipulation, and an empirical knowledge of the effects of temperature, doubtless acquired after long experience and many failures, which confer on the carmines of some makers a greater lustre than on those of others. The use of carmine has of late years been extended to the manufacture of superfine red inks, of artificial flowers, and to silk dyeing. Carmine is the finest red colour which the painter possesses. It is chiefly used in miniature painting and in water colours. It is made in large quantities in Paris. [See Cochineal, App.]

Carmine is one of those colours called *lakes*, a term applied to certain colouring substances, which behave like acids and combine by precipitation with a white earthy basis, usually alumina. Carmine is the richest and purest portion of the colouring matter of cochineal isolated in the manner here alluded to. But cochineal contains various colouring matters all capable of acting the part of an acid; these matters are very soluble in water: with insoluble bases they form insoluble salts, but with potash, soda, and ammonia, they form soluble ones. Hence, if cochineal be heated with potash, soda, or ammonia, all its colouring matters will be obtained combined with the base employed in solution with a little albumen. If a quantity of acid be now added, not sufficient to set at liberty all the colouring matters dissolved, the one which has the greatest tendency to unite with the albumen will be precipitated alone, or nearly so.

The manufacture of carmine admits of explanation on these principles. The cochineal is generally boiled with carbonate of potash or soda, and the solution is precipitated by means of a weak acid or an acid salt. If the latter be small in quantity the precipitate is pure carmine, but it forms a powder of such extreme tenuity that it is not deposited by repose only, unless several days be allowed for the purpose. To expedite the process, white of egg or fish-glue is employed, exactly in the same manner as if the object were to clarify the liquid. These two substances in coagulating collect the carmine, and form with it a combination more or less clotty, which is deposited in the course of a few minutes.

The various kinds of carmine are distinguished by numbers, and possess a value corresponding thereto; the difference depending either on the proportion of alumina added in the precipitation, or on the presence of vermilion added for the purpose of diluting and increasing the quantity of the colour: the alumina produces a paler tint, and the vermilion a tint different from that of genuine carmine. The amount of adulteration can always be detected by the use of liquor ammoniæ, which dissolves the whole of the carmine, but leaves the adulterating matters untouched, so that by filtering the solution, and drying and weighing the solid residuum, the amount of adulteration can be detected. The ammonia solution of carmine forms a beautiful transparent colour, making a superior description of red ink.

We give a few recipes for the manufacture of carmine:—

To make ordinary carmine, take 1 pound of cochineal in powder; $3\frac{1}{2}$ drachms of carbonate of potash; 8 drachms of alum in powder, and $3\frac{1}{2}$ drachms of fish-glue. Boil the cochineal and the potash in a copper containing 60 pints of water, the boiling being allayed from time to time with cold water. After boiling for about 20 minutes, the copper must be taken from the fire and placed on a table at such an angle that the liquor may be conveniently poured. The pounded alum is then thrown in and the decoction stirred. It immediately changes colour and inclines to a more brilliant tint. In the course of a quarter of an hour, the cochineal is deposited at the bottom and the liquor becomes quite clear: it contains the colouring matter and probably a little alum in suspension. The liquor is decanted into a copper of the same size as the first, and being placed over a fire, the fish-glue is added: this must be previously dissolved in a large quantity of water and strained. At the moment boiling begins the carmine rises to the surface and a coagulum is formed. The copper must be instantly removed from the fire and its contents be stirred with a spatula. In 15 or 20 minutes the carmine is deposited: the supernatant liquor must then be decanted, and the deposit of carmine drained upon a filter of fine canvas or linen. The carmine ought to crush readily under the fingers. The liquor after the precipitation of the carmine is still charged with colour, and may be employed for making *carminated lakes*, (also called *Lake of Florence, Paris*, or *Vienna*.) For this purpose newly precipitated alumina is added to the liquor, the mixture is stirred, and heated a little, but not too much. When the alumina has absorbed the colour, the mixture is allowed to settle and the liquor is drawn off.

The *process of Alxon* or *Langlois* is thus described: Raise 30 pints of river water to the boiling point: then throw in 1lb. of cochineal, and add a filtered solution of 6 drachms of carbonate of soda and 1lb. of water: let the mixture boil for half an hour; remove the copper from the fire and let it cool, inclining it on one side. Add 6 drachms of pulverized alum, stir with a brush to quicken the solution of the salt, and let the whole rest 20 minutes. The liquor, which has a fine scarlet colour, is to be carefully decanted into another vessel: the whites of 2 eggs well beaten up with half a pound of water are to be added and stirred up with a brush. The copper is again to be placed on the fire, when the alumina concreting will carry the colouring matter with it. The copper is to be removed from the fire and left at rest for 25 or 30 minutes, to allow the carmine to fall down. When the supernatant liquor is drawn off, the deposit is placed upon a cloth filter stretched upon a frame, to drain. When the carmine has the consistence of cream cheese it is removed from the filter with a silver or ivory knife, and set to dry upon plates covered with paper to secure it from dust. By this process a pound of cochineal gives an ounce and a half of carmine.

The process of Madame Cenette of Amsterdam, is said to afford an article of such extraordinary lustre as to fatigue the eye. Into 6 pails-full of boiling-hot river water, throw 2lbs. of the finest cochineal in powder; continue the ebullition for 2 hours, and then add 3 oz. of refined saltpetre, and after a few moments 4 oz. of salt of sorrel (binoxalate of potash). In 10 minutes more, take the copper from the fire and let it settle for 4 hours; then draw off the liquor with a siphon into flat glazed earthen vessels, and leave it there for 3 weeks. There is formed upon the surface a pretty thick mouldiness, which is to be removed dexterously in one pellicle by a slip of whalebone. Should the film tear, and fragments of it fall down, they must be removed with the utmost care. Then decant the supernatant water by means of a siphon, the end of which may touch the bottom of the dish, because the layer of carmine is very firm. Whatever water remains must be sucked away by a pipette. The carmine is then cautiously dried in the shade.[1]

Various imitations of carmine are prepared for the use of those who exhibit rouge on their cheeks. The common rouge of the theatres is prepared by pounding benzoin, red sandal wood, Brazil wood and alum in brandy. The mixture is then boiled until three-fourths of the liquid has evaporated: a paint of an intense red colour remains, and this is applied to the face with a piece of soft cotton. Vinegar is sometimes substituted for the brandy; but as both fluids injure the skin, the colouring matter is sometimes extracted from the dye-woods, and unguents formed therewith, by means of balm of Mecca, butter of cacao or spermaceti. If the colour be too intense it is mixed with chalk.

Rouge dishes are small saucers containing a layer of dry rouge. Those which are prepared in Portugal probably contain genuine carmine: clumsy imitations of these dishes are prepared in London.

Spanish wool and *oriental wool* are also rouge vehicles. Wool is impregnated with the colour, and formed into cakes about the size of a crown-piece by the Spaniards, and somewhat larger by the Chinese: the latter is most esteemed, since it affords (in the language of a modern pharmacopist) "a most lovely and agreeable blush to the cheek."

Beautifully painted and japanned *colour-boxes* are also imported from China. Each box contains 24 papers, and in each paper are 3 smaller ones, namely, a "lovely blushing red" for the cheeks, an "alabaster white" for the face and neck, and a "jet black" for the eyebrows.

French carmine is superior to that of English manufacture, and the superiority is said to depend on the influence of light on its formation and precipitation; the clear sky of the south of France being more favourable for the process than the more hazy atmosphere of England. On this subject Sir Humphry Davy relates the following anecdote:—"A manufacturer of carmine, who was aware of the superiority of the French colour, went to Lyons for the purpose of improving his process, and bargained with the most celebrated manufacturer in that capital for the acquisition of his secret, for which he was to pay a thousand pounds. He was shown all the processes, and saw a beautiful colour produced; yet he found not the least difference in the French mode of fabrication and that which he had constantly adopted. He appealed to the manufacturer, and insisted that he must have concealed something. The manufacturer assured him that he had not, and invited him to see the process a second time. He minutely examined the water and the materials, which were the same as his own, and, very much surprised, said, 'I have lost my labour and my money, for the air of England does not permit us to make good carmine.' 'Stay,' says the Frenchman, 'do not deceive yourself. What kind of weather is it now?' 'A bright sunny day,' said the Englishman. 'And such are the days,' said the Frenchman, 'on which I make my colour. Were I to attempt to manufacture it on a dark or cloudy day, my result would be the same as yours. Let me advise you, my friend, always to make carmine on bright and sunny days.' 'I will,' says the Englishman; 'but I fear I shall make very little in London.'"[2]

CARPENTRY, the art of framing timber for the purposes of architecture, machinery, and all structures in which any considerable weight or pressure is to be supported.

The carpenter who wishes to understand the mechanical principles upon which his art depends, must make himself acquainted with the general laws which regulate the *composition* and *resolution of forces.* The following are illustrations of this important branch of mechanical science.

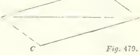

Fig. 479.

If a body, or a portion thereof, be at the same time pressed by two forces, in the directions of the two lines A B, A C, Fig. 479; and if the lengths of these lines be in the proportion of the intensities or magnitudes of the two forces; the body is affected in the same manner, as if it were pressed by a single force acting in the direction A D, which is the diagonal of the parallelogram A B C D, having for its adjacent sides the two lines A B, A C. And further, the intensity or magnitude of this single force (or resultant, as it is termed,) will bear the same proportion to the two original forces, that the length of the line A D does to the lengths of the two lines A B, A C. This is called the *composition of forces.*

Hence, also, a single force or pressure acting in the direction A D, and represented in magnitude by the length of the line A D, may be resolved into two other forces, acting in the directions A B, A C, and represented in magnitude by the lengths of the lines A B and A C respectively; the lines A B, A C, being the adjacent sides of any parallelogram, of which A D forms the diagonal. This is called the *resolution of forces.*[3]

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(1) "Annales de l'Industrie," Férussac's *Bulletin.*

(2) "Salmonia; or, Days of Fly-fishing."

(3) See "Mechanics applied to the Arts," by the Rev. H. Moseley p. 29; also, Hann's "Mechanics for Practical Men," p. 5

This result may be verified by means of a couple of small pulleys, some thread, and some weights. To the threads A *d*, A F *b*, and A E *c*, Fig. 480, attach the weights *b*, *d*, *c*, and let two of the threads be passed over the pulleys F, and E. The knot A will be drawn in the directions A B, A C, A K. If the sum of the weights *b*, and *c*, be greater than the single weight *d*; the threads will arrange themselves into a certain determinate form: if the knot A be pulled out of its place, it will return to it again, and will not rest in any other position. If, for example, the three weights be equal, the threads will always make equal angles of 120° each, round the knot. If one of the weights be 3 pounds or ounces, &c., another 4, and the third 5; the angle opposite to the thread stretched by 5 pounds or ounces, &c. will always be square. When the knot A is thus in equilibrio, we must suppose that the action of the weight *d* in the direction A *d*, is in direct opposition to the compounded action of *b* in the direction A B, and of *c* in the direction A C. If, therefore, we produce *d* A to any point D, and make A D, on any scale of equal parts, to represent the magnitude of the force or pressure exerted by the weight *d*; the pressures exerted on A by the weights *b*, and *c*, in the directions A B, A C, are equivalent to a pressure acting in the direction A D, whose intensity is represented by A D. If we now measure off by the same scale on A F and A E, the lines A B and A C, having the same proportions to A D that the weights *b* and *c* have to the weight *d*, and if we draw D B, and D C, we shall find D C to be equal and parallel to A B, and D B equal and parallel to A C, so that A D is the diagonal of the parallelogram A B D C. This will always be the case, whatever weights be used, only the weight *d* must be less than the sum of the other two: if any one of the weights exceed the sum of the other two, it will prevail, and drag them along with it. Now, as the weight *d* just balances an equal weight *g*, pulling directly upwards by the intervention of the pulley G, and as it just balances the weights *b*, and *c*, acting in the direction A B, A C; we infer that the knot A is affected in the same manner, by those two weights or by the single weight *g*, and therefore, that two pressures acting in the directions and with the intensities A B, A C, are equivalent to a single pressure having the direction and proportion of A D. So also the pressures represented by A B, A K, are equivalent to A H, which is equal and opposite to A C. Also A K and A C are equivalent to A I, which is equal and opposite to A B.

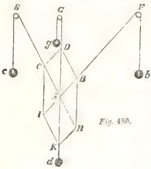


Fig. 480.

To apply this composition of pressures to a case of construction:—Suppose an upright beam B A to be pushed in the direction of its length by a load B; that this beam abut on the ends of two beams, A C, A D, which are firmly resisted at their extreme points C and D, by resting on two blocks: these two beams can only resist in the directions C A, D A, and therefore the pressures which they sustain from the beam B A, are in the directions A C, A D. To ascertain how much each sustains, produce B A to E, taking A E from a scale of equal parts, to represent the number of tons, pounds, or other units of weight in the load B, by which B A is pressed. Draw E F and E G parallel to A D and A C; then A F measured on the same scale will give the number of pounds or other assumed units, which acts as a compressing or crushing force on A C, and A G will give the thrust on A D. The length of A C or A D has no influence on the thrust arising from the pressure of B A, the directions remaining the same; but the effects of this thrust are modified by the length of the piece on which it is exerted. This force compresses the beam, and will therefore compress a beam of double length twice as much, and this may change the form of the combination. If A C, for example, be much shorter than A D, it will be much less compressed: the piece C A will turn about the centre C, while D A will hardly change its position; and the angle C A D will become more open, the point A sinking down. The change of shape resulting from these mutual pressures requires to be carefully studied, for by such a change strains may be produced in places where there were none before, and may tend to break the beams across. The dotted lines show another position of the beam A D′. This greatly increases the thrust on A D′ and A C. That on A D′, now represented by A G′, is almost doubled, and that on A C, now shown by A F′ or G′ E, instead of by A F or G E, is nearly four times greater than before. Thus a very moderate force A E may produce an enormous strain, when it is exerted on a very obtuse angle.

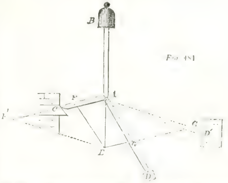


Fig. 481

Figs. 482, 483, will show how the same thrusts A F, A G, are made on these beams by a weight hanging from a billet resting on A, pressing hard on A D, and also leaning a little on A C, as in Fig. 482: or by an upright

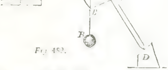


Fig. 482.

piece A E, joggled on the two beams A C, A D, and performing the office of an ordinary king-post, as in Fig. 483. It will of course be seen that the proportions of these forces will be the same, if the system

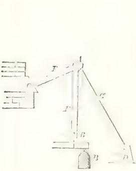


Fig. 483.

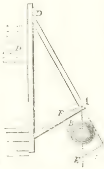
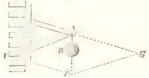


Fig. 484.

be inverted, and each beam be strained or pulled in the opposite direction; that is to say, if the thrusts be converted into strains or tensions. Thus the rope and weight, or loaded beam, instead of being supported by two struts, as in Figs. 481, 482, 483, may be upheld by a framing such as in Fig. 484. Here the batten D A is stretched by a force A G, and the piece A c is compressed by a force A F. The magnitudes of these forces remain unaltered, but one of them, A G, is converted from a thrust into a strain.

By changing the form of this framing, as in Fig. 485, we produce the same result as in the system represented by the dotted lines, Fig. 481, and the forces acting on both the battens AD, AC, are now greatly increased. In short, the more open the angle C A G against which the push is exerted, the greater are the forces which are brought on the struts or ties forming the sides of the angle.

Fig. 485.



Should there be any difficulty in ascertaining whether a piece is compressed or extended, whether it is a *strut* or a *tie*, we must consider whether a rope could be employed in its place or not. Thus, in Fig. 486, a rope could evidently be used instead of the piece AC; but AD is a strut butting on the block D, and manifestly could not be replaced by a rope. If A C be placed in the position represented by the dotted lines, the compression of A D is now A G′, and the force stretching A C′ is now A F′, both much greater than they were before. This system is similar to that shown by the dotted lines Fig. 487. There will be no doubt which of these several pieces are subject to tension, and which to compression. A C and A C′, Fig. 486, A D, A C, and A C′, Fig. 487, could be replaced by ropes, and are therefore extended. A D, Fig. 486, could not, and is therefore compressed.

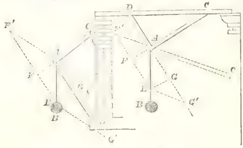


Fig. 486. Fig. 487.

Fig. 487 is the inversion of Fig. 482; and the dotted position A C′, by opening the angle C A D, leads to the same changes as are described in reference to Figs. 481, 485.

Such are the chief varieties in the bearings of three pieces on one point. "All calculations about the strength of carpentry are reduced to this case; for when more ties or braces meet in a point, (a thing that rarely happens,) we reduce them to three, by substituting for any two the force which results from their combination, and then combining this with another, and so on."

The following rule may be given for distinguishing between a strut and a tie:—From the point on which the straining force acts, draw a line in the direction in which this force would move, if left at liberty. Then if this line fall within the angle formed by the two supporting pieces, both pieces are compressed. If it fall within the angle formed by producing the directions of the supporting pieces, then both are extended. If it fall within the angle formed by one piece and the direction of the other produced, then the piece, the direction of which was produced to form the angle, is extended, and the other piece is compressed.

By scientific reasonings such as these, Professor Robison[1] was the first to raise carpentry from a mechanical art to the rank of an applied science. For further information we must refer to his valuable work, and also to that of Tredgold,[2] and pass on to a few general remarks before we close our brief examination of the principles of carpentry.

Since a triangle is the only figure which cannot change its form without altering the proportions of its sides, all frame-work should be arranged in a triangular system, or be divided into triangles, by ties and struts.

When a system of framing is employed to augment the strength of a single beam, such a combination is called a ***truss***, and the beam itself is said to be *trussed*.

As a general rule in carpentry, the stiffness or resistance to change of form of any framework, is of greater importance than the comparative strength; which last can be more easily ensured, by increase of or additions to the strength of parts.

But as an universal axiom it must be remembered,

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(1) "Robison: System of Mechanical Philosophy." Edited by Brewster. Vol. i. 1822.

(2) "Tredgold: Elementary Principles of Carpentry." Third Edition by P. Barlow. 4to. London. 1840.

that the strength of no system of framing can exceed that of its weakest point.

Here we may distinguish between the carpenter, and the joiner. The carpenter frames and puts together roofs, partitions, floors, and other essential parts of the building. The joiner only commences where the carpenter leaves off, by supplying and fitting stairs, cupboards, furniture, and other parts, necessary but not essential to the building.

The next branch of carpentry to which we shall devote a brief glance, is that of *Joints.* These may be classed as—

1. Joints for lengthening timbers, by connecting pieces end to end.
2. Framing and bearing joints used in trusses, floorings, &c.
3. Joints for ties and braces.

Timbers may be connected lengthwise, where neatness is not an object, by simply bringing the two beams end to end, placing a short piece on each side, and bolting through these short pieces and the main beams. This form of joint is not neat, but it is simple, and if bolts and straps are well applied, it is as good to resist transverse as longitudinal strains. Ship-carpenters call it "fishing" a beam.

But where neatness is an object, beams are connected longitudinally by *scarfing.* In this case half of the substance of each beam is cut away for a certain length, and the cut portions being brought together, are fastened by screws, bolts, straps, or wedges. In designing the scarf, due regard must be had to the nature of the strain the piece is intended to resist, whether longitudinal, transverse, or both combined.

The common scarf joint, Fig. 488, is made by merely halving each piece of timber for a certain length, and then bolting or strapping the two pieces together. This has evidently no strength in resisting longitudinal strains, beyond that of the bolts and the adhesion or friction between the two timbers which they may cause. But more elaborate joints may be made, (see Figs. 489 to 493,) in which the resistance of the wood to splitting is brought in, either with or without bolts, to bear the strain. Figs. 491 and 493, are good examples of this kind of joint. These are to be drawn together when made by a key or by double wedges. Such a key is shown in the middle of the joint 493, and its place is indicated by dotted lines in 491. Such joints might be used without bolts or straps, but they are far safer with them.

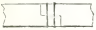
Fig. 488.

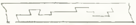
Fig. 489.

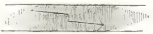
Fig. 490.

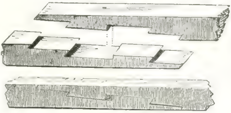
Fig. 491.

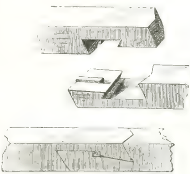
Fig. 492.

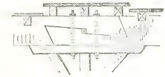
Fig. 493.

Fig. 494, shows the French scarf called "*traits de Jupiter,*" from its fancied resemblance to the form of a flash of lightning. This figure shows the mode of applying bolts and straps. If such a joint were made to resist a transverse and downward strain, it would be better to terminate the upper and right-hand end of the scarf by a plain butt end, of half the depth of the timber, to omit the indents on each side of the centre, and apply a key or folding wedges to the middle indent, making a half dovetail to the lower and left-hand end of the scarf. The reason of this change will be obvious, if we remember, that with a transverse strain the upper surface is only compressed, and the lower surface only extended. The right-hand strap might also in such case, be advantageously removed to the place of the left-hand bolt.

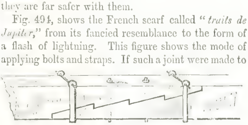
Fig. 494.

Figs. 495, 496, show longitudinal joints which may be used where a vertical pressure only is to be borne. The joint is made very short, as the only object is to

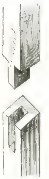
Fig. 495.

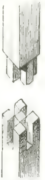
Fig. 496.

keep the two pieces in the same line. In Fig. 496, the end of each piece is divided into nine squares. Five of these being cut away in one piece, and the four alternate squares in the other, the two ends fit into one another.

A common method of scarfing bond and wall plates is, to cut about three-fifths through each piece on the upper face of the one and the under face of the other, about 6 or 8 inches from the end, transversely, forming what is called a *kerf;* and longitudinally from the end, from two-fifths down on the same side; so that the pieces lap together like a half dovetail.

The following brief summary of practice, in scarf joints, is taken from Barlow's "Tredgold's Carpentry."

The length of the scarf should be, if bolts are not used—

In oak, ash, or elm, six times the depth of the beam.

In fir, twelve times the depth of the beam.

If bolts and indents are combined, the length of the scarf should be—

In oak, ash, or elm, twice the depth of the beam.

In fir, four times the depth.

In scarfing beams to resist transverse strains, straps driven on tight are better than bolts.

The sum of the areas of the bolts should not be less than one-fifth the area of the beam, when a longitudinal strain is to be borne.

No joint should be used in which shrinkage or expansion can tend to tear the timbers.

No joint can be made so strong as the timber itself.

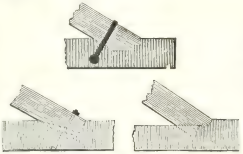

Fig. 497. PRINCIPAL RAFTERS.

Framing joints are those used in the construction of trusses, roofs, centres for bridges, &c. They are universally made on the principle of a *tenon* and *mortise,* that is, one of the pieces to be joined is cut away so as to leave a small projection termed a *tenon,* and a corresponding cavity, called a *mortise,* is formed in the other piece to receive this tenon.

The tenon may be very short, so as not to pass through the other piece, as shown in Figs. 498, and 501. The use of such a tenon is only to prevent any lateral motion in the pieces joined together. Such a joint would be made at the connexion of a king- or queen-post with the principal rafters, (Figs. 499, 500, upper parts of the figures), or of the king and queen-posts with the struts, (see the lower parts of the same figures.) The ends of king- and queen-posts are usually tenoned into the tie-beams. With a similar view, to prevent lateral displacement, the feet of the principal rafters of a roof are tenoned into the tie-beam (Fig. 497). As the pressure in this case is very oblique to the surface of the tie-beam, a bolt and nut, or, better still, a stirrup-iron or strap, is commonly used, as shown in the figure.

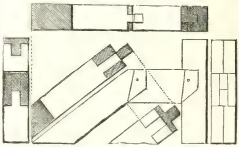

Fig. 498. BEVELLED SHOULDER-JOINTS.

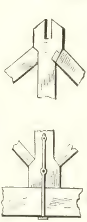

Fig. 499. KING-POSTS.

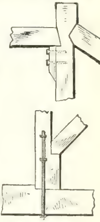

Fig. 500. QUEEN-POSTS.

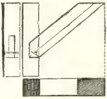

Fig 501.

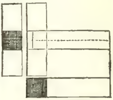

Fig. 502.

A very short tenon, called sometimes a *stub-tenon,* is used at the feet of uprights in partitions and bearers for floors (Fig. 503).

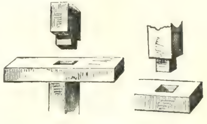

Fig. 503.

When tenons have not only to resist lateral displacement, but also a strain tending to draw them from their mortises, they must be *pinned* or *wedged.* An oak pin or trenail, or an iron bolt, may be driven through both the tenon and the sides of the mortise, as in Figs 498 and 501; or the tenon may be cut so long as to extend quite through the mortised piece, and have a cross pin passed through the projecting part. The last plan is commonly used in connecting *trimmers* or bridging-joists to the girders or main-joists in floorings.

Wedging is done by making the tenon long enough to pass just through the mortised piece. A saw-cut is made in the projecting part, and a small wedge being driven in, the end of the tenon is expanded, and cannot be again withdrawn from the mortise. If the piece cannot be mortised quite through, *fox-tail wedging* may be adopted. The tenon is made to fit the mortise exactly; two cross saw-cuts are made in its end, and small wedges are put loosely into these. When the tenon is driven down, the wedges meet the bottom of the mortise, are forced into the tenon, expanding its end, and the whole is fixed very firmly. The feet of king- and queen-posts (see lower part of Figs. 499, 500) are commonly tenoned into the tie-beam. Sometimes the tenon is cut to a half dovetail form, and the mortise-hole made to correspond. A key or wedge, driven between the straight side of the tenon and the straight side of the mortise, forces the sloping parts together, and fixes the tenon in its place. A stirrup or strap, such as shown in Figs. 499, 500, is far more trustworthy than such a joint, however well made at first.

Tenons are usually made one-third of the thickness of the timber they are cut from.

Framing and bearing joints should have their bearing surfaces as large as possible, and cut, if possible, at right angles with the direction of the pressure, or (where one piece bears in the direction of its length upon another) in a circular arc, so as to distribute the pressure equally over the bearing surface.

The strength of a structure must never be made to depend on the stiffness of joints, but solely on the arrangement of its timbers. No joint can be made so good as by its own stiffness or resistance to motion to add anything to the strength of heavy framing.

Under the head of joints for ties and braces, we may include joints in wall-plates, purlines, &c. Wall-plates are very commonly joined by dovetailing, as shown in the left-hand figure 504; but they are much better if *halved* together, as in the right-hand figure, and pinned or bolted through. Dovetail joints should, in fact, never be depended upon in carpentry, where the grain of one piece of wood crosses that of the other. Timber shrinks far more across the grain than in the direction of its length: therefore dovetails, however well made at first, are liable through shrinkage to become loose, and thus throw all the strain on the pins or bolts, which were intended only to assist the joint. Dovetails can only be used with advantage when, as in joinery, and in the cases shown in Figs. 507 and 508 (left-hand figure), the grain of both pieces runs the same way. The shrinkage of one then counterbalances the contraction of the other, and the joint remains firm. Such cases rarely occur in carpentry.

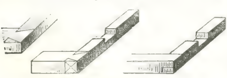

Fig 504.

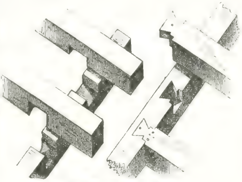

Fig. 505. CAULKING JOINTS.

Tie-beams are connected to wall-plates by *cogging* or *cocking*. A shallow notch is cut out of the under surface of the beam, of the width of the wall-plate, and a similar notch cut in the wall-plate, to receive the beam. The two notches fit together, and all motion, longitudinal or transverse, is prevented. Such a joint is shown in Fig. 505 (left-hand figure). The right-hand figure shows a common way of connecting flooring-joists with trimmers or main joists. As there is seldom in such cases any great force tending to tear the joists from the trimmers, the dovetail form may suffice for all that is wanted. Such a joint would do for a brace between two girders or main joists, where a thrust inwards was alone to be apprehended.

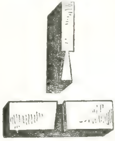

Fig. 506.

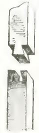

Fig. 507.

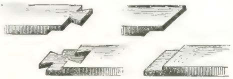

Fig. 508. NOTCHING.

Fig. 509 shows a manner of fitting in a brace on each side of a beam. This joint is only adapted for pressure inward. If any force tending to separate the pieces be feared, the cogging shown in Fig. 510 may be used.

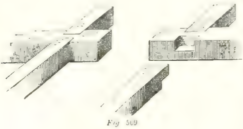

Fig. 509.

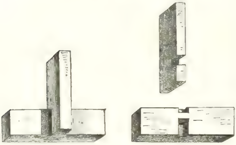

Fig. 510.

Purlines are notched down on the principal rafters, as shown in Fig. 505 (left-hand figure).

Fig. 506 shows another application of the dovetail joint, to which the remarks already made will also apply.

Two pieces are said to be *lapped* together, when a portion of each is cut away, and the cut surfaces brought together, as in Fig. 508.

For a more detailed description of the various joints used in carpentry, and an inquiry into their respective values, see Barlow's "Tredgold's Carpentry," quoted above.

For further information on this subject we refer to the articles FLOORS AND PARTITIONS; JOINERY; ROOF; TIMBER;—and to the sections of the article BRIDGE devoted to *Centres* and *Timber Bridges*.

The following definitions of some of the most important terms used in Carpentry, will be found useful.

Wall-plates, also called *raising-plates;* pieces of timber laid on the wall, in order to distribute equally the pressure of the roof, and to bind the walls together, (*a, a, a, a,* Figs. 511, 512).

Tie-beam; (*b, b,* Figs. 511, 512) a horizontal piece of timber connected to two opposite principal rafters: it answers the double purpose of preventing the walls from being pushed out by the thrust of the roof, and of supporting the ceiling of the rooms below. When placed above the bottom of the rafters it is called a *collar-beam*.

Principal rafters; (*c, c, c, c,* Figs. 511, 512) two pieces of timber in the sides of the truss, supporting a grated frame of timber over them, on which the covering or slating rests.

Purlines; (*d, d, d, d,* Figs. 511, 512) horizontal pieces of timber notched on the principal rafters, and on which and the pole-plates the common rafters rest.

Common rafters; (*e, e, e, e,* Figs. 511, 512) pieces of timber of small section, placed equidistantly upon the purlines, and parallel to the principal rafters: they support the boarding to which the slating is fixed.

Pole-plates; (*f, f, f, f,* Figs. 511, 512) pieces of timber resting on the ends of the tie-beams, and supporting the lower ends of the common rafters.

King-post; (*g,* Fig. 511) an upright piece of timber in the middle of a truss, framed at the upper end into the principal rafters, and at the lower end into the tie-beam: this prevents the tie-beam from sinking in the middle.

Struts; (*h, h, h, h,* Figs. 511, 512) oblique straining pieces framed below into the king-posts or queen-posts, and above into the principal rafters, which are supported by them: or sometimes they have their ends framed into beams, that are too long to support themselves without bending. They are often called *braces*.

Queen-posts; (*i, i,* Fig. 512) two upright pieces of timber framed below into the tie-beam, and above into the principal rafters; placed equidistantly from the middle of the truss or its extremities.

Puncheons; short transverse pieces of timber fixed between two others for supporting them equally; so that when any force operates on the one the other resists it equally, and if one break the other will break also. These are sometimes called studs.

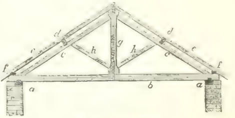

Fig. 511. KING TRUSS.

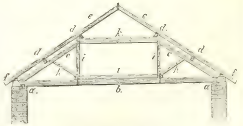

Fig. 512. QUEEN TRUSS.

Straining-beam; (*k,* Fig. 512) a piece of timber placed between two others called *queen-posts*, at their upper ends, in order to withstand the thrust of the principal rafters.

Straining-cill; (*l,* Fig. 512) a piece of timber placed upon the tie-beam, at the bottom of two queen-posts, in order to withstand the force of the braces which are acted upon by the weight of the covering.

Collar-beams; horizontal pieces of timber made sloping, on the upper edge, from the middle towards each end, in an obtuse angle, for discharging the water. They are placed above the straining-beam in a truncated roof, for supporting the boarding on which the lead is laid: their ends run 3 or 4 inches above the sloping plane of the common rafters, in order to form a roll for fixing the lead.

Auxiliary-rafters; pieces of timber framed in the same vertical plane with the principal rafters, under, and parallel to them, for giving additional support. They are sometimes called *principal braces*, and sometimes *cushion-rafters*.

CARPET, see WEAVING, Sec. v. See also APPENDIX.

CARRIAGE, see WHEEL CARRIAGE.

CARTHAMUS or SAFFLOWER, the petals of the *Carthamus tinctorius* or *Bastard Saffron*. It grows naturally in Egypt, and is cultivated largely in Spain and in many parts of the Levant, whence it is chiefly imported. It contains a red colouring matter insoluble in water, and called *carthaméine*, derived probably from the oxidation of a peculiar principle existing in the petals called *carthamine*, and by Dumas, *carthamous acid*. When a weak soda solution of carthamine is left in contact with oxygen, it first becomes yellow and then red, and on saturating this red liquor with citric acid, red carthaméine is thrown down. When air is excluded the alkaline solution remains colourless. "The affinity of carthaméine for cotton and silk is such, that when it is recently precipitated, those substances immediately combine with it, and become at first rose-coloured, and afterwards of a fine red, so that they may be thus dyed without the intervention of a mordant; the stuffs so dyed are rendered yellow by the alkalis, and the colour is to a certain extent restored by the acids. Carthaméine is never used in dyeing wool. When it is precipitated from concentrated solutions, it furnishes a liquid paint, which evaporated upon saucers, leaves a residue of somewhat metallic lustre, used as a pink dye-stuff, and which, mixed with finely powdered talc and dried, constitutes common rouge.[1] [See CARMINE.]

Safflower also contains a yellow substance soluble in water. When the infusion is evaporated it leaves an extract very soluble in water, precipitated by acids and soluble in alkalis. It is not reddened by oxidizing agents.

CARTRIDGE, a cylindrical case of strong paper, (manufactured for the purpose, and hence called *cartridge-paper*,) containing a charge of powder only, (in which case it is termed *blank* cartridge,) or ball and powder, (*ball*-cartridge,) or powder and shot. The use of cartridge is to expedite the loading of small arms. Large cartridges for cannon and mortars, containing powder only, are cased with flannel, pasteboard, or wood. Thin sheet-lead has also been used, and is much to be preferred to the other substances, which are apt to leave burning particles behind in the piece after it has been fired, thus endangering the persons who serve the gun. Wire shot cartridges without powder are also used. They consist of an inner case of wire net-work inclosed in a thin paper case, to the outer end of which a wadding is attached. The shot mixed with bone-dust to fill up the interstices is put into this case, which is rammed down upon the charge of powder. On firing the gun the paper case is immediately torn to pieces, and the shot begin to pass out through the meshes of the net-work, which is carried forward until all the shot are dispersed. By this contrivance the charge leaves the barrel like a bullet, and prevents the leading of the gun,[2] and lessens the recoil. The shot are also carried so much more closely than when loose, that lighter charges and consequently a lighter gun may be used; time is saved in loading, and as the cartridge has no tendency to move until the gun is fired, the danger arising from the accidental shifting or rising of loose charges is avoided.

Mr. Caffin has invented a machine for filling cartridges, which consists of two measures, *m m*, Figs. 513, 514, fixed vertically in a circular plate opposite to each other with an axis between them, on which they work between two other plates. On the top plate *p p* a hopper *h* is fixed, communicating alternately with the measures and filling them; and on the opposite side in the bottom plate *p′* is a hole with a spout *s*, through which the discharge takes place. The plates are framed together by three pillars *r r*, having double adjusting nuts *n n* on each to regulate the distance of the plates. The measures are moved by a handle or lever *l*, the motion of which is limited by the pins *a a*, which, while it presents one under the hopper to receive, places the other immediately over the discharging hole for delivery; so that the two operations of filling and discharging are going on at the same time. The bottom of each measure is slightly contracted to retard in a small degree the discharge, and thus secure the filling of one measure before the other is emptied. A hole is cut in the top plate over the discharging measure, by which it may be ascertained that it is always full, as well as that the whole contents are delivered. A boy delivers with ease

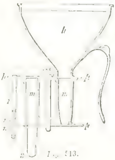

Fig. 513.

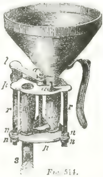

Fig. 514.

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(1) Brande's Manual of Chemistry, p. 1503. See also Dumas, Chimie appliquée, &c. viii. 57.

(2) The streaking of the interior of the barrel by the lead of the shot or bullet.

12,500 measures daily from one machine, and supplies the hopper himself. This machine is also available for measuring seed, corn, or any article in which struck measure is necessary.[1] [See APPENDIX.]

CARVING BY MACHINERY is an art designed to save time and cost in the production of decorative wood-work, and at the same time to multiply the copies without lessening the value of original designs. This art is intended to perform the same part with respect to the most beautiful specimens of the wood-carver's skill as copper-plate engraving does for the finest paintings of antiquity. These noble works of genius, confined to their respective galleries, are yet made widely known to the untravelled and unlettered public of all nations through the medium of good engravings; and so may the same public now enjoy, through the wondrous advance of wood-carving by machinery, a sight of that which represents the skill of a Gibbons, or some other laborious artist of former days. It may be said, indeed, that the cases are not parallel; for that, while the engraving can never be confounded with the painting which it represents, nor in any way enter into competition with it, the carving by machinery, being performed in the same material, and with almost identical results, really becomes a *fac-simile* of the original, and must therefore deteriorate its value. Making all allowance for this difference, it yet remains evident that machinery can only imitate, not invent; and therefore the position of the original designer is maintained, while his works are better known to fame by these facilities of repetition. It is also to be remembered that the work of the machine is only partial, and that the finer details are still delivered over to be performed by hand. On the whole, therefore, the invention of wood-carving by machinery must be considered as an advantage to the art, by diffusing more and more widely a taste for works of this kind, by allowing the rarest and best of them to become known, and also by giving employment to a larger number of artists than were previously required.

These benefits are chiefly due to the talent and ingenuity of Mr. T. B. Jordan, to whom the gold Isis medal of the Society of Arts was presented by His Royal Highness Prince Albert, the President, in 1847, for inventing, arranging, and bringing into successful operation such machinery as was capable of producing or assisting in the production of every class of carving, so as to copy accurately any solid form which the mind of the artist can conceive, or his hand execute.

Previously to Mr. Jordan's invention, there had been many attempts of a similar kind, which, from want of economy in production, or from being applicable only to a limited class of subjects, never came into general use. The only machine which has been successfully applied is one for the production of ivory miniatures, copied from full-sized models. The mode of doing this is kept a secret by the inventor, Mr. Cheverton; but the results are exquisite, and are sufficient in themselves to show that works of high art may be successfully copied by machinery. It is conjectured that the means by which these reduced copies are obtained is somewhat on the principle of the pantograph.

The description which follows will assist the reader in comprehending the general method of carving by machinery according to Mr. Jordan's plan; and, as it respects the more elaborate carvings, such as figures, fruits, and flowers, in which a large amount of under-cutting is required, apparently beyond the power of any machine to accomplish, we quote Mr. Jordan's own anecdote on that point:—"Our method of accomplishing this undercutting and carving on the round I cannot better exemplify than by telling you one of the arguments which was very triumphantly used against its possibility, at a scientific meeting at Hampstead, last winter, where I exhibited a few early specimens of our work. Having assured a gentleman present that the undercutting of the specimen he was examining was done on the machine, he smiled, and said 'No: that is not possible; we cannot get a gun to shoot round a hay-mow.' I replied, 'True: but if the engineer takes the liberty of turning the hay-mow about on a point, will not a fixed gun point to every corner in succession?'" Thus, whatever the subject may be, there is provision made in this most successful invention for its being completely and cleverly copied, the high finish alone being afterwards put in by the hand of the experienced carver in wood.

The machine, of which Fig. 515 is a pictorial view, and Fig. 516 a front elevation, consists of two principal parts. The first, or horizontal part, is the *bed-plate* and *floating table*, on which the work and the pattern are fixed, all the motions of which

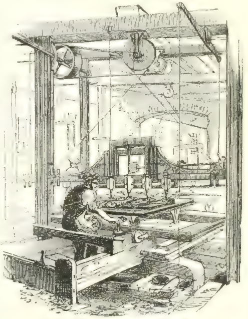

Fig. 515. CARVING MACHINE AT WORK.

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(1) Transactions of the Society of Arts, vol. xlv. 1827.

are horizontal. The second, or vertical part, is that which carries the tracing and cutting tools, the only motion of which, except the revolution of the cutters, is vertical. If, now, the vertical part be placed in contact with the horizontal, while the latter is moved about horizontally, in all directions, a figure will be described on the latter corresponding to the direction of its motion, as if, in drawing with a lead pencil, the pencil were fixed, and the paper moved about against it. Such is the principle of Jordan's machine. We shall now describe its parts separately.

The horizontal part consists of three castings:—*first*, the bed-plate A B C D, which is a railway permanently fixed to the floor of the shop, and made perfectly horizontal; *secondly*, a carriage or frame, I J K L, running on this railway, supported by four wheels, of which only two are seen, F D; *third*, the horizontal table, M N O P, which carries the work, and is called the *floating table*: this is furnished with four wheels, running on the frame I J K L, but its motion is at right angles with the motion of the frame. We are thus enabled to move the floating table either laterally, on its own wheels, or straight forwards or backwards, by the frame I J K L, and thus bring any point in the floating table to any point in the same plane with it. The workman moves the floating table from right to left with his left hand by the wheel U, and the table and frame are both moved backwards and forwards with his right hand on the horizontal wheel, as shown in Fig. 515.

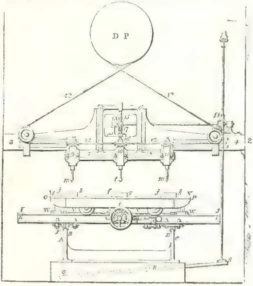


Fig. 516.

The second or vertical part of the machine consists of a bridge or fixed support, 1 2 3 4, in which a bar, 5 6, slides up and down, with another, 7 8, fixed to it. To the latter are attached any required number of mandrils, 9, 10, 11, one of which carries a blunt tool or *tracer*, Fig. 517, which is fixed, and the others carry each a cutting tool, Fig. 518, (calculated by their revolution to describe the shape of the tracer.) These tools are made to revolve from 5,000 to 7,000 times a minute by means of an endless band, 12, driven by steam. The model *f g* is fixed on the floating table under the tracer, and a piece of wood, *j k*, or other material to be carved, is fixed under each cutter. The cutters and tracer are adjusted to the same level, and the steam is turned on. The man presses on the pedal R S, which acts by means of a horizontal bar carrying two pulleys, 13 and 14, on the slide, and lowers it to the work. There is generally a weight to counterbalance the slide, so that it cannot press heavier than is desirable. 15 is a stop screw, which regulates the range of the slide, to which it is fixed. It passes through a free hole in the bracket 16, which serves as a stop to the locking-nuts 17, and these may be fixed on any part of the screw, so as to determine the distance through which the slide shall move. In very large machines the workman has a greater command over the floating table, by means of a steering-wheel U, and its axle, which passes across the centre of the lower rolling frame, and is furnished with a drum 3 or 4 inches in diameter, about which is coiled the centre portion of a wire line V V, while its ends are fixed to screws W W, which pass through sockets cast on the floating table; so that, by turning the steering-wheel to the right or left, a corresponding motion will be given to the work just inside the steering-wheel; and on the same axis there is a small cogged wheel, which serves to fix the axle, and consequently to stop the motion from right to left when the detent shown in the figure is dropped into its cogs. There is a similar steering-wheel and detent for the other motion; but the detents are only used when straight lines in one direction are required. The workman moves the floating table about, so as to bring every part of the pattern under the tracer, and as the slide can only move vertically, whenever the tracer comes to a depression it goes down, and the cutters cut a similar depression in the blocks. If there be an elevation in the model, it lifts up the tracer, and with it the cutters, and thus an elevation of the same height is left in the blocks; and in this way the work proceeds, the tracer gliding silently over the model, and the cutters cutting away with some noise on the blocks, until the pattern is finished. The more accurately the model is to be copied, the more delicate are the tools employed; but it is generally desirable to perfect the work by hand, as there must necessarily be little delicate portions which it is impossible for a machine to perform cor-

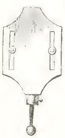


Fig. 517.

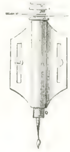


Fig. 518.

rectly. Such is the method employed in common carving; but when a large amount of undercutting is required, some modifications of the machinery are necessary. These consist either in placing the wood to be cut between two centres or chucks on the floating table, and turning it round, so as to get at all the parts in succession, or in using crooked tools and tracers, something like inverted mushrooms, when a small amount only of undercutting is required. As a proof of the value of Mr. Jordan's machine, we may mention that the beautiful and elaborate wood-carving which adorns the new Houses of Parliament has been produced by its means.

CASE-HARDENING, an operation of great importance in the arts, whereby a thin casing of steel is given to iron, and the steel can be hardened to that particular depth, leaving the central parts in their original condition of soft fibrous iron or of cast-iron.

Steel is formed by the chemical combination of a small proportion of carbon with iron. In case-hardening the carbon is communicated to the iron by means of certain animal matters, such as the hoofs, horns, bones and skin in a charred or coarsely pounded state, sometimes with the addition of a little salt. The works to be case-hardened should be surrounded on all sides with a layer from $\frac{1}{2}$ to 1 inch thick.

In case-hardening a gun-lock, for example, the work is inserted into the bone-dust contained in a sheet-iron case; the lid is tied on with iron-wire, and the joint luted with clay: it is then heated to redness as rapidly as possible, and kept at that heat for half an hour or an hour. The contents are then quickly immersed in cold water. The effects intended to be produced are a steely exterior, and a clean surface covered with mottled tints caused probably by oxidation.

Some malleable iron-castings, such as snuffers, &c., are case-hardened, because in that condition they admit of a better polish. They should be left in the burnt bone-dust at a dull red heat about 2 or 3 hours, and should be quenched in oil, which renders them less brittle than in water. Thin articles are sometimes not only case-hardened, but entirely converted into steel of an inferior kind, which makes them very brittle.

For large works the process is continued from 2 to 8 hours, and is even repeated a second time with new materials. In some cases the work is immersed in water directly it leaves the furnace: in others the box is allowed to cool without being opened, and the pieces are hardened by a subsequent operation. [See ANNEALING.]

When the case-hardening is required to terminate at any particular part, as a shoulder, &c., the object is left with a band or projection, and the work is allowed to cool without being immersed in water, the band is turned off, and the work when hardened in the open fire is only affected where the case-hardened surface is left.

A salt known as prussiate of potash ($C_2 + N$) has of late years been used for case-hardening, and it shortens the time required for the process from hours into minutes. For example, the iron is heated in the open fire to a dull red-heat, and this salt is either sprinkled upon it or rubbed upon it in a lump: the iron is then returned to the fire for a few minutes, and then immersed in water. By rubbing the salt upon any particular part of the article, that part alone is case-hardened. By this process the case of steel is exceedingly thin, and it is even said to be not continuous.

In most cases the thickness of the steel does not exceed $\frac{1}{10}$th inch, nor is it necessary that it should be thicker, the object being to obtain durability of surface with strength of interior. The steel obtained in this manner is not equal to that which is converted and hammered in the usual way. [See IRON, Sec. vii.]

CASHMERE, a beautiful fabric manufactured in the kingdom of Cashmere, from the fine wool growing about the roots of the hair of the Thibet goat. Cashmere shawls have a wide-spread fame, on account of their extreme softness, brilliancy, and elegance; and it has long been the aim of European nations to imitate, and if possible to equal them, applying to their manufacture the more speedy and elaborate methods which modern science has placed within reach. The oriental shawls are woven by an extremely slow process, and are therefore very costly. The date of the manufacture is unknown, but these shawls have been celebrated ever since the British established themselves in India. As far as we can gather from the observations of various writers, the Thibetian wool, being imported from Thibet and Tartary into Cashmere, is first bleached to rid it of a greyish hue which naturally belongs to it, then spun into yarn by women, and dyed of various colours. The yarn is next given out to the weavers by a merchant, who perhaps enters largely into the shawl trade, and engages a number of shops in which men work for him; or else he supplies a certain number of overseers called Oostands with yarn, delivering to them at the same time instructions as to the quality, colour, patterns, &c. of the goods, and these men carry on the manufacture at their own houses, with the help of ordinary weavers. The Oostands receive six or eight *pice* a day for their wages, the common workman from one to four *pice*, the value of a *pice* being about three-halfpence. Thus scantily are the shawl weavers of Cashmere rewarded, while the fabric they produce has often been sold in London at from 100*l.* to 400*l.* the shawl. But it is fair to state that the manufacture of a remarkably fine and elaborate shawl will sometimes occupy a shop for a whole year, two or three or perhaps four persons being constantly engaged on it. Plain shawls are simply woven with a long narrow and heavy shuttle, but variegated shawls are worked with wooden needles instead of a shuttle, there being a separate needle for each colour. In some of the richest shawls, scarcely a quarter of an inch is completed by three persons in one day. Sometimes, in order to hasten the process, a shawl is made in separate pieces at different looms, and the pieces are afterwards sewed together. This is done with great dexterity, so that it is not immediately detected. An overseer at each loom superintends the workmen, and if the pattern be new, he directs them as to the figures and colours, keeping before him a paper pattern of the device which is to be produced. The rough or inferior side of the shawl is uppermost on the frame, nevertheless the pattern is most accurately preserved by the workers, who sit on benches while so employed. The shawls are made both long and square, the former generally measuring 54 inches wide, and 126 long, the latter 63 to 72 inches square. They are exquisitely soft and warm, surpassing in these respects every other clothing material. In some parts of Asia these shawls are worn just as they come from the loom; but all those destined for India are carefully washed and packed near Lahore. The extent of the manufacture in Cashmere has been differently stated: some years ago there were said to be 16,000 looms in that kingdom; and if it be correct that about five shawls (including the inferior qualities) are made on an average at each loom during the year, this gives a total of 80,000 shawls as the annual produce of the kingdom. When Cashmere was tributary to Afghanistan, a considerable portion of the revenue was exacted in shawls instead of money.

The beauty and value of Cashmere shawls has led to various imitations, which at length have proved successful, both in France and England. The government of the former country gave encouragement to a patriotic and zealous man, M. Jaubert, who exposed himself to great risk and hardship, in bringing from the East in 1823 a flock of Thibet goats, part of which were successfully reared at St. Ouen, near Paris. The climate suited them well, so that for several years the proprietor was enabled to sell a great number of male and female goats, which were called Cashmere goats.

At the time when the flock first arrived in Paris, an English gentleman (Mr. Taylor) was so fortunate as to obtain four of the goats by purchase. These he safely conveyed to Essex, and, placing them in his park, they continued in health, and steadily multiplied, until, in 1828, the number had increased to twenty-seven, and, in 1833, to fifty. The coat of these animals was a mixture of long coarse hair and of short fine down. The latter became loose early in April, and was easily collected by combing the goats two or three times; but the down produced was very small in quantity, not more than four ounces being obtainable each season from a male, and two ounces from a female. This circumstance, which made it hopeless to cultivate the Cashmere goat for any profitable purpose, led to a mixture of the Cashmere breed with another breed with abundant silky hair, introduced into France a few years later, and called Angora goats. The progeny of the two, called Cashmere-Angora goats, were found to possess a considerable quantity of long silky down, admirably fitted for the purpose of shawl-weaving. Some of these goats yielded as much as thirty ounces of down per goat, while the animals were more robust and easily nourished than the pure Cashmere. From these experiments great good has resulted in the improvement of various flocks. For instance, ten male and three female Cashmere-Angora goats were shipped for South Australia, where the wool trade has become highly important, from the judicious importations of fine Saxon and other flocks into that country. The Cashmere wool still imported from Thibet comes into Europe by way of Casan, on the eastern bank of the Volga. The mills for spinning it are very numerous in France, where three principal descriptions of Cashmere shawls are manufactured, at Paris, Lyons, and Nismes. The Paris shawls are principally of the kind known as French Cashmere, in which, by the aid of the draw-loom and of the Jacquard, a surface appearance is given precisely similar to that of the oriental shawls. Both the warp and the weft are the yarn of pure Cashmere down: the figures and colours of the Indian shawls are faithfully copied, and the deception would be complete, did not the reverse side show the cut ends. What is called the Hindoo shawl, manufactured at Paris, has its warp in spun silk, which reduces the price. These imitation shawls are executed by as many shuttles as there are colours employed, which are thrown across the warp according to the requirements of the pattern, and being in many cases introduced only at intervals, the yarn remains floating loose at the back of the piece, and is cut off afterwards.

To contrive a method of weaving shawls that should be, like the eastern ones, both sides alike, was a difficult task, but was at last accomplished by Parisian ingenuity. In this case, the yarns of the weft are not only equal in number to the colours of the pattern, but there are also as many little shuttles or pirns filled with these yarns as there are colours to be repeated in the breadth of the piece. Each of these small pirns or bobbins passes through only that portion of the flower in which the colour of its yarn is to appear, and stops on the one side and the other of the cloth exactly at its limit: it then returns upon itself, after having crossed the thread of the adjoining shuttle. From this reciprocal interweaving of the various yarns of the shuttles, it happens that, although the weft is made up of a great number of different threads, yet they form a continuous line in the whole breadth of the web, upon which the lay or batten acts in the usual manner. The great art consists in avoiding confusion of the shuttles, and in not striking up the lay till all have done their part. A woman assisted by two girls is able to conduct the whole operation. But this close imitation of the oriental shawl is a very slow process, and therefore the shawls must be necessarily costly. Lyons is famous for its Thibet shawls, the weft of which is yarn, with a mixture of spun silk. The shawls of Nismes are celebrated for their low price and the ingenuity with which spun silk, Thibet down, and cotton are all worked up together. [See APPENDIX.

CASK, see COOPERAGE.

CASSAVA, see STARCH.

CASTING and FOUNDING. The valuable property of fusibility possessed by many of the common metals, admits of their being poured in a fluid state into moulds of various kinds, so that on again becoming hard by cooling, the castings are the exact counterparts of the moulds. In casting ingots, flat plates, and a few other objects, open moulds are used; but metals are generally cast in close moulds which must contain apertures or *ingates*, for pouring in the metal and for the escape of air. If the moulds be of metal, they must be warmed before pouring, so that the fluid metal may not be chilled and solidified before it has filled every part of the mould; and when the moulds are of earth or clay, the moisture which is necessary in forming them must be expelled before the time of filling. Earthen moulds must also be porous, to allow of the escape of any vapours or gases which may be generated at the time of pouring, otherwise the molten metal may be driven out with a violent explosion, or some of the bubbles of air will displace the fluid metal, and render it spongy or porous, in which case the casting is said to be *blown*. Sand is sufficiently porous to allow of the escape of vapour. In the greater number of cases moulds consist of two parts only: in other cases they are divided into many parts.

When an object is to be cast, it is often necessary to form an exact pattern in wood, and the success of castings depends greatly on the skill of the pattern-maker. Deal, pine and mahogany with a straight grain are the best woods for making patterns. In putting the parts together, screws are preferred to nails, but glue-joints, such as dovetails, tenons, dowels, &c. are also used. The patterns are made to taper a little in the parts which enter most deeply into the sand, so that they may be easily removed. Sharp internal angles should also be avoided, as they leave a sharp edge or axis in the sand which is liable to be broken down in the removal of the pattern, or injured by the rushing in of the fluid metal. All glue must be carefully scraped off, or it will adhere to and pull down the sand. The patterns should either be painted, varnished or well brushed with black-lead. Foundry patterns are sometimes made in metal, and when of iron they are allowed to get a little rusty, and then warmed sufficiently to melt bees'-wax, which is rubbed over them; after which most of the wax is removed by polishing with a hard brush. Wax is also used for stopping up any little holes which may exist in wooden patterns. Whitening is also used for the same purpose. Metal patterns must sometimes have holes tapped in them for receiving screwed wires which serve as handles for lifting them out of the sand. Large wooden patterns also have screwed metal plates let into them for the same purpose.

The moulding-sand is supported by shallow iron frames without tops or bottoms called *flasks*. The bottom 4, 5, Fig. 519, is supposed to be rammed full of sand, and to stand upon a flat board 6. The model of the flat bar shown in the figure which is to be cast is laid on the surface of the sand, and that of the round bar is embedded half way therein. The mould is then dusted with dry *parting-sand*. The top part of the flask 2, 3, is shown still empty, and in the act of being attached to 4, 5, by its pins, which fit exactly into corresponding holes in 4, 5. The part 2, 3, is also rammed full of sand and covered with a top board 1, not shown in the figures. The sand of course receives the impression of the patterns, and when the mould is opened, the models are removed, and channels for the escape of air are scooped out from the ends of the cavities left by the models, to the hollows or pouring holes at the end of the flask. The parts are then replaced in the order 1 to 6, and the whole are fixed together as in Fig. 520. The flask is then placed almost erect near the pouring trough, and the metal is poured in from a crucible, as shown in Fig. 222, [see BRASS,] but if the flask be small, it is propped up with a short bar on the surface of the pouring or spill trough.

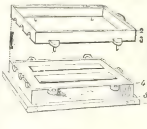


Fig. 519.

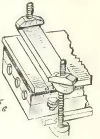


Fig. 520.

The flasks or casting boxes are of various sizes, and the depth of each side is about 2 or 3 inches. For small castings they are poured at the edge as already explained, but for large castings they are generally poured horizontally through a hole in the top. The tools used in making the moulds are a sieve, shovel, rammer, Fig. 521, strike, mallet, a knife, and two or three loosening wires, and small trowels, Figs. 522, 523. The moulds are made of fine sand and loam. Those used in the metropolis are obtained from Hampstead, and also from Lewisham. Common moulds are made of old damp sand, and they are generally poured while damp or *green*, but sometimes they are dried on the face. The old sand is much less adhesive than the new, and of a dark brown colour from the admixture of brick-dust, flour, charcoal-dust, &c., used in moulding. New sand and loam are occasionally added to the old stock, so that when moistened slightly, and pressed firmly in the hand, it may become moderately hard and compact. Red brick-dust is commonly used as *parting sand*, to prevent the separate portions of the damp sand in the two halves of the flask from adhering together. The face of the mould which receives the metal is generally

Fig. 521.

Fig. 522.

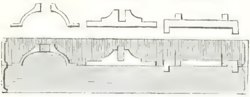
Fig. 523.

dusted with meal-dust or waste flour; or in large works with powdered chalk, wood, or tan-ashes. For the finest brass castings the moulds are faced with charcoal, rottenstone, or a mixture of the two, and dried over a dull fire of cork shavings, or smoked over pitch or black rosin lighted in an iron ladle. Gold and silver casters use a lighted link for facing their sand moulds: metallic moulds are sometimes smoked over a lamp; the object being in each case to deposit a fine layer of soot upon the moulds.

Where much loam is used, the moulds must be thoroughly dry before pouring, which is not generally necessary with ordinary sand moulds. The best castings are however obtained when the sand contains a good deal of loam and moisture, and has been closely rammed; but in such cases there is always a risk of accident, from the moist and impervious condition of the mould, and the resistance to the escape of air and vapour. The founder gets over this difficulty to a certain extent by using a little facing-sand, containing rather more loam, for the face of the green moulds. Iron-founder's sand is coarser, and therefore more porous than that of the brass-founder, and may be used in a moister state. As the castings contract considerably in cooling, it is also important in large and slight works, not to ram the face of the mould too strongly, or its strength may exceed that of the red-hot metal while in the act of contracting, and hence the casting would be rent or torn asunder from the restraint of the mould: whereas the metal ought to pull down the face of the sand instead of being itself injured.

When the objects to be cast contain one hole or several holes, they are said to be *cored*, and various methods are used for introducing internal moulds or cores, so as to intercept the metal at those parts. In pewterer's moulds pins are inserted for producing holes in the joints. In Figs. 524, 525, 526, the upper figures represent sections of the three models or casting patterns, and the lower figure represents the two halves of the mould, the top half being shaded with perpendicular, the bottom with horizontal, and the cores with oblique lines, while the white open spaces show the hollows to be filled up by the fluid metal. When the cavity extends through the model, and exactly represents that which is required in the casting, as in Fig. 524, the work is said *to deliver its own core.* If the hole be sufficiently taper, it delivers its own core, as a continuation of the general mass of sand filling one side of the flask, but in many cases, the space in the model is rammed full of strong sand at first, and is then moulded as if to produce a plain solid casting. Before the mould is closed for pouring, the sand core is carefully pushed out of the pattern, and inserted in its proper place in the mould, which is indicated by one side of the core being scored with one or two deep marks, which produce similar marks in the mould. When the hole extends only partly through, as in Fig. 525, the hole of the pattern is filled with a solid plug of soft unburnt brick; the core is made long enough to project about as much as its own diameter, and the work is moulded as if to be cast with a solid pin instead of a hole. The core is then extracted and inserted into the hollow which it has itself formed in the flask. Patterns for iron-work are mostly made with *prints* instead of holes as in Fig. 526. The pattern maker places round or square pieces on one or both sides of the pattern, where the holes are required, and the founder has moulds for forming cores of corresponding diameters and sections, and in lengths of from 2 to 12 inches, short pieces of which are cut off as required.

Fig. 524. Fig. 525. Fig. 526.



Figs. 527, 528, represent the moulds for casting a pewter inkstand. They consist of four parts, the black portions representing the sections of the inkstand to be cast. The moulds consist each of a top piece or cap *t*, a bottom or core *b*, and two sides or cottles *s s*. In Fig. 528, one side is removed in order to expose the casting, and the top piece *t* is supposed to be sawn through to make the whole more distinct.

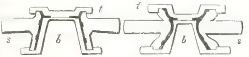


Fig. 527.

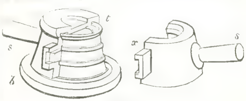


Fig. 528.

The top and bottom parts have each a rebate like the lid of a snuff-box, which embraces the external edges of the two side pieces *s s*, and the latter divide as in a bullet mould, exactly upon the diametrical line of the inkstand, which in a circular object is the largest part. In this way the positions of the parts are strictly maintained. When the mould has been put together, laid upon its side, and filled through *x* the ingate or *tedge*, it is allowed to stand a minute or two. The top *t* is then knocked off with a mallet; the mould is then held in the hand, and the centre part knocked out of the casting by the edge. The two sides are then pulled asunder by their handles, and the casting is removed from the one in which it happens to stick fast; but it requires cautious handling not to break it. The face of the mould is slightly anointed with red ochre and white of egg, to prevent the metal from adhering, and to give the works a better face. The first few castings are generally spoiled until the mould becomes warm.

In moulding patterns which are undercut, *false cores* are used, as in Fig. 530. It is evident that all the patterns in the mould, Fig. 529, can be extracted

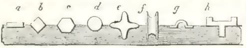


Fig 529.

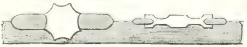


Fig. 530.

from each half of the mould, because none of them, when partly buried, extends beyond the line which separates the two parts of the flask: *a* and *b* could be laid in exactly upon the diagonal, or upon one flat side or partly embedded; *f g h* might be sunk more or less into the mould, their sides being perpendicular; but the patterns in Fig. 530 being undercut, the division of the mould into two parts only would be impracticable, and false cores or further subdivisions would be required in the manner shown in the figure.

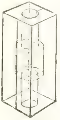


Fig. 531.

Many works require core-boxes to be made expressly for them, as in Fig. 531, where the dotted line shows an enlargement in the centre for coring a hole of that particular section. *c*, *d*, Fig. 532, represent the two halves of a brass or lead core-box used in casting the stop-cock; *a* represents the core after its removal from the part *c*, in which it is also figured. In *b*, the model from which the object is moulded, the shaded parts represent the projections, or *core-prints*, which imprint within the mould the places where the extremities of the core, *a*, are supported when placed therein.

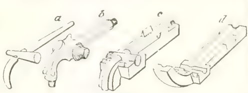


Fig. 532.

In the casting of figures, such as busts, animals, branches, foliage, &c., much skill is required. The originals are generally solid, but the moulds are divided into many parts. The complexity of such moulds may be judged of from works in plaster of Paris, which are sometimes sold before the seams of the mould have been removed. In all figured works approaching to the circular or elliptical section, the mould must be divided into at least three parts, except under very favourable circumstances. In the human figure and quadrupeds, the four limbs and the trunk require at least three parts each, and often many more. Piece after piece of the mould is successively produced, each piece embracing so much of the figure as in no part to require any core to overhang the line in which it is withdrawn. "The side of the mould in which the figure is partly embedded is first dusted with charcoal, and then the first core is very carefully rammed into the nook, and pared down to the new line of division. The green or wet sand-core is then dusted, and the second core is made, and afterwards dusted, when the moulder proceeds with the third core, and so on; each being carefully adapted to its neighbour, and withdrawn, to see that all is right, before the succeeding core is proceeded with. The relative positions of the cores amongst themselves are readily maintained and recognised by the irregularity of their forms, as in a child's dissected map, only making a notch or two here and there, which are faithfully copied in the succeeding piece. It is frequently necessary to thrust two or more broken needles through the green cores in the neighbouring parts to connect them together, in imitation of the pins in the flasks. All the parts of the mould are dried in an oven, and the facings are smoked over a cork fire; the perfection of the casting is augmented by pouring whilst the mould is still slightly warm, as otherwise on cooling it has an increased affinity for damp; but the mould when hot is more or less filled with the aqueous vapour, which is equally prejudicial.

"When a figure such as a bust is required to be cast hollow from a solid model, it is first moulded exactly as above. The core is now produced as follows:—At the foot of the bust a large space, nearly equal in length and bulk to the bust, is cut away in the sand, to serve for fixing the core in the mould, or for the *balance*, as it is called, as the core cannot be propped up at both ends. The entire hollow, that is, for the bust and the balance, is filled with a composition of about one part of plaster of Paris, and two of sand or fine brick-dust, mixed with a little water, and poured in fluid, a few wires being placed amidst the same for additional support. The mould is now taken to pieces to extract the core, which is then dried, thoroughly burned, and allowed to cool slowly, (which the founder calls *annealing*, from a similar method being employed in annealing or softening the metals, glass, &c. [See ANNEALING.]) The core is then returned to the mould to see that it has not become distorted. If needful, the filling around the balance is made good to suit the reduced magnitude of the core, which is then so far pared away as to leave room for the thickness of the metal. This is frequently regulated by boring holes at many parts of the core with a stop-drill, having a collar to prevent its penetrating beyond the determined depth. The surface of the core is now cut down to the bottom of the holes as uniformly as possible. When the mould has been faced, dried and smoked, &c., the whole is put together for pouring, for which purpose the figure is inverted, and filled from the pedestal. Equestrian and other figures are sometimes cast in two, three or more pieces, and joined together by solder, screws, or wires; but in all such works, the aim of the founder is to leave little or nothing for the finisher or chaser to do." [1]

Small animals, insects, parts of vegetables, &c.,

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(1) Holtzapffel, "Mechanical Manipulation."

may be cast by the following contrivance. The objects are fixed in the centre of a small box by means of a few threads attached to any convenient parts, one or two wires being added to make air-holes and ingates for the metal. A small quantity of river silt or mud, carefully washed, is first thrown in and spread around the object by swinging the box about; and when partly dry, successive but coarser coats are thrown in, so as ultimately to fill the box. When it has become thoroughly dry, the wires are drawn out, and the mould is then burnt, so as to reduce the object to ashes, and when every particle of the model has been blown out, the mould is ready to be filled with metal.

This method has been improved on by Mr. Henry Dircks, who has found that by making his model in wax and then surrounding it with plaster-of-Paris, or other sufficiently plastic or hardening mould, the application of heat will cause the wax to be absorbed by the plaster, leaving the plaster cast quite sharp, pure and unsullied, having no waxed or oily appearance even where the wax was fully $\frac{1}{16}$th of an inch thick.—The plan is as follows:—Sheets of wax are cut and formed into any required shape, as usual in making wax flowers, &c., or in some cases the wax itself may be moulded or shaped to any particular form; and when the whole is arranged and put together, on a board covered with wax, air vents are formed by attaching the ends of waxed threads to the wax foundation, and the other ends to the loftiest points in the object, most suitable for the purpose. It must be remembered that the plaster mould will have to be turned upside down, and that when dry and warm from a suitable drying oven, the lower ends of all these threads will be uppermost and can be withdrawn, having shrunk from the loss of wax; which substance will also have been absorbed by every part of the mould, or where thick and in quantity may partly be run out. By using stearine and resin, with perhaps a little Burgundy pitch, a cheap substitute for wax is obtained. In forming wreaths, &c., as no colouring is required, the artist has only to attend to form, dimensions, and general arrangement. The copper castings obtained by this improvement, may be coated with the precious metals by means of electrotyping.[1]

A method of producing plates for printing copies of ferns, sea-weed, &c., has been invented by Dr. Branson of Sheffield, and is thus performed. A piece of gutta percha, free from blemish, and of the size of the plate required, is placed in boiling water: when thoroughly softened it is taken out and laid flat upon a smooth metal plate, and immediately dusted over with the finest bronze powder used for printing gold letters. The object of this is threefold; to dry the surface, to render the surface more smooth, and to prevent adhesion. A frond of fern, algæ, or similar flat vegetable form is then neatly laid out upon the bronze surface and covered with a polished metal plate, either of copper or of German silver: the whole is then subjected to an amount of pressure sufficient to imbed the upper plate in the gutta percha. When the gutta percha is cold, the metal plate is removed and the fern gently withdrawn from its bed. From the beautiful impression of the fern left in the gutta percha a cast in brass may be readily taken. As soon as the surface of the brass cast has been burnished, (of course carefully avoiding the impression,) it is ready for the copper-plate printer. If the printer skilfully mixes the ink to the tint of the fern, a print is obtained scarcely to be distinguished from the plant itself. The novelty of the process consists in causing the plant, so to speak, to engrave itself, and also in the substitution of a cheap casting in brass for an expensive copper-plate engraving. Electrotype plates may be deposited on the bronzed gutta percha, and a similar result obtained, but the brass casting answers equally well, and has the advantage of being more durable, cheaper, and expeditious.[2]

The process of moulding in sand is similar whether the castings be brass or iron; but the large size of many iron castings gives rise to certain differences in detail. In most cases the iron-founder moulds and casts his works horizontally, with the flasks lying on the ground. In the largest works the lower part of the flask is omitted, such pieces being moulded in the sand which forms the floor of the foundry, in which case the position of the upper flask is denoted by driving iron stakes into the earth in contact with the internal angles of the *lugs* or projecting slips of the flasks. As the sand would fall out of large flasks when lifted up, a number of cross bars containing S-shaped hooks are inserted, and both bars and hooks are wetted with thick clay-water. Some flasks require the strength of two or several men to lift them, for which purpose iron handles are made to project from the sides of the flask. Very heavy flasks are lifted by means of a crane.

The sand of the iron-founder, as already noticed, is coarser than that of the brass-founder. The parting sand is the burned sand which is scraped off the castings; the facing sand is sometimes equal parts very fine coal dust and charcoal dust, with the addition in some cases of old or new sand, or a little road-drift. All these substances get mingled with the sand of the floor, and lessen its binding quality. This is remedied by the addition of new sand, or by using more moisture. Before extracting the patterns, the founder sometimes wets the edges of the sand with a sponge with a nail tied to it, to direct the water in a fine stream. For heavy works, a watering-pot is used.

The flasks are poured through a hole in the upper half, formed by placing a wooden runner-stick in the top part while it is being rammed full of sand, and a small channel is afterwards cut sideways into the mould. In some cases, a single casting requires two, three, or more runners; as where a great weight of metal is required, or where the casting is large but slight, as in trellis-work, because, in such cases, the metal might cool before the mould is full, if introduced only at one runner.

The iron-founder adopts all the methods of coring

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(1) Communication to the Athenæum, No. 1212.

(2) Communication to the Athenæum No. 1208.

used by the brass-founder, and others which are not much used in brass-works, such as lateral holes in the parts of the castings buried beneath the general surface of the mould. The following example, from Mr. Holtzapffel's work, will illustrate this. Fig. 533 represents the finished casting; Fig. 534 the model of the same; Fig. 536 the appearance of the bottom flask or drag, when the pattern is first removed, and Fig. 535 the flask and cores, when closed ready for pouring. The moulds are inverted, and the same letters refer to similar parts of each figure. The core-print *a* would deliver from the sand, and leave the cavity at *a*, Fig. 536, to be afterwards filled by the core, shown black in Fig. 535, just the same as explained in Fig. 526. But the core-print *b*, Fig. 534, which may be compared with the black stud *b*, Fig. 535, would tear away the sand above it in withdrawing the pattern; and therefore the print is made to extend to the neighbouring face of the pattern or the parting line, as at *e*, Fig. 535. This being the case, the pattern would leave the space denoted by Fig. 535; the core is put down sideways to the bottom of the recess, and extends entirely across the same; the small open space above is made good with the general surface, as shown by the shaded lines in Fig. 535, and this filling in at the same time fixes the core precisely where directed by the print *d*, which latter has a mark to denote to the moulder where the core is to end. The circular hole requires the core-print shown at *c*, Fig. 534, and the cores themselves are made in core-boxes, as before explained in the case of Fig. 531.

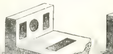
Fig. 533.

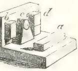

Fig. 534.

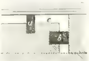

Fig. 535.

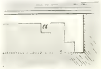

Fig. 536.

Fig. 537 represents the model and core-print from which the finished casting, Fig. 538, may be made, from a solid pattern in a two-part flask: it would be inverted, and the parting would be made upon the line *x*. The print for the holes *a a* would be placed in the top flask, and those for the great apertures or panels *d* would be made in a core-box of the express form, and as thick as the pattern and core-print measured together. The core would be deposited edgewise into the core-print, and the upper corners of the mould would be made good, as explained in Fig. 535.

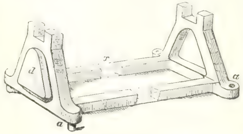

Fig. 537. Fig. 538.

The iron-founder makes frequent use of flasks which divide into three or four parts, for the purpose of increasing the depth of the contained space. It is also sometimes necessary to make the casting in some respects different from the patterns. If, for example, the pattern be too long, or it is desirable to obliterate some parts temporarily, the mould is made of the full size and *stopped off*, additional sand being worked into the mould by means of a trowel and a piece of wood, to represent the imagined termination of the pattern. If, on the contrary, the casting is to be longer than the pattern, the additional piece is frequently cut off the mould with a trowel, &c. Some common works, such as plates, gratings, parts of ordinary stoves, &c., are made to *written* measures, without patterns, in which case a few parallel slips of wood represent the margin of the casting, and these are arranged upon a flat body of sand, which is modelled almost entirely by hand.

As iron castings contract in cooling, at the rate of about the 95th to the 98th of their length, or nearly 1 per cent., it is necessary to make the patterns somewhat larger than the intended castings. This allowance is made by employing a *contraction rule*, which is made like a surveyor's rod, but one-eighth of an inch longer in each foot than ordinary standard measure. In this way, in measuring out the pattern, the increased dimensions are given without entailing the trouble of calculation. If, however, an *iron* pattern is to be made from a wooden pattern, so as to serve for the permanent foundry pattern, a *double* contraction-rule is employed for making the wooden pattern: in this rule there is a quarter of an inch in excess in each foot.

"To lessen the distortion of castings, from the unequal contraction in the cooling, it is important that the models should be nearly symmetrical. For example, bars or rods of all the sections in Fig. 529 may be expected to remain straight: perhaps *g* is in the most danger; but if the lower fins of *e* and *h* were removed, their flat surfaces, then exposed to the sand, would become rounding or convex in length, from the contraction of the upper rib being unopposed by a similar piece on the other side. Bars and beams, the sections of which resemble the letter **I**, are of the most favourable kind for general permanence, and also for strength. Large panels may be cut out from their central ribs, to diminish their weight, without materially reducing their stability. They are very much used, not only in building, but also in the framing of machinery, which is in a great measure based upon the same rules. It is also of great importance, especially in castings of large size, that the *thickness* of the metal should be nearly alike throughout, so that it may cool at all parts in about the same time. Should it happen that one part is set or rigid while another is semi-fluid, or in the act of crystallizing, there is great risk either of the one part being altogether torn from another and producing fracture, or, should the disturbing force be insufficient to break the casting, it may strain the metal nearly to its limit of tenacity or elasticity, so that a force far below that which the casting should properly bear may break it in pieces." This irregular contraction is partly prevented by uncovering the thick parts of the casting, or by cooling them by throwing on water from watering-pots.

As wood or metal patterns are very expensive, especially when the number of castings of the particular pattern is but few, this costly, and in some respects uncertain, method of casting is avoided, where it is practicable, by a simple and ingenious application of the art of turning, called *loam-moulding*. In casting a steam-cylinder, for example, the following method is adopted, and will be understood by referring to the figures. Fig. 539 is the entire section of the first stage; Figs. 540 and 541 are the half sections of the second and third stages, preparatory to burying the mould in the pit in which it is to be filled. The inner part of the loam mould is called the core, in small works, and the *nowel* in large: the outer part is the *case* or *cope*. Each part is built upon an iron loam-plate, or a ring rough on the face, and with four ears by which it may be lifted. Sometimes the mould is erected on four shallow pedestals of bricks, for the convenience of making a fire beneath it, to dry the loam. It may also be made upon a low truck, upon which it can be wheeled to the loam-stove, heated to 300° or 400°. A vertical axis *a* is mounted in two holes in the truck, or in a pedestal or socket erected thereon: or it may pass through a hole in the loam-plate, or in any bearing attached to the roof, &c. The first step is to fix on the spindle, by means of clutches or binding-screws, the templet *b b*, at the distance of the radius of the cylinder. An inner cylinder of brickwork is then built up, plastered with soft loam, (shaded black in the figures,) and scraped into the cylindrical form by the radius-board being moved round on its axis. When the surface is smooth, it is thoroughly dried, then covered with blackwash, and again dried. The charcoal-dust in the blackwash serves as a parting, to prevent the succeeding portions of the loam mould from adhering to the first. The templet *c c*, Fig. 540, cut exactly to the external form of the cylinder, is next attached to the axis, at the distance from the core required for the thickness of the metal. Additional loam is thrown on to form the thickness, which is carefully smoothed: the templet and spindle are then dismounted, and the thickness (represented white) is also dried and blackwashed. The ring for the outer case or cope is now laid down, and its position is denoted by fixed studs or by marks, and the brickwork shown in Fig. 541 is built up of bricks and loam, with an inner facing of loam, worked accurately to the turned thickness. The new work on the cope being thoroughly dried, is lifted off carefully by means of the crane and a cross-beam with 4 chains, Fig. 542. This process drags off the thickness, which usually breaks, and any remaining pieces are carefully picked out of the cope: both parts of the mould are then repaired, and again blackened and dried. The mould is next put together in a pit sunk in the floor of the foundry, and the two iron plates are screwed together, the surrounding space being rammed hard, to prevent the mould from bursting open; but the inner part is left in a loose state, for the escape of air, &c. The top edges of the mould are covered over with a *loam-cake*, previously dried, or a ring, 3 or 4 inches thick, perforated with holes, as at *d*, Fig. 541, for the entry of the metal and the escape of the air.

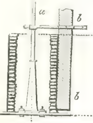

Fig 539.

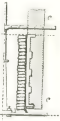

Fig. 540.

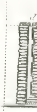

Fig 541.

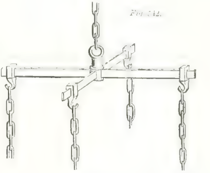

Fig. 542.

The large cylinders of the Cornish pumping engines, of 80, 90, and 95 inches bore, and 12 or 14 feet long, and the blowing cylinders of blast furnaces, sometimes 105 inches bore, are made without using the thickness. The case or cope is built up in the pit and turned inside with a radius bar, and the core is erected on a plate on the floor and turned outside to a gage: when dried, it is lowered into the other by a crane. They are cast about a foot longer than is required, to make the top edge sound, and this additional length is cut off before boring. To enable the mould to resist the pressure of the column of fluid metal, (equal at the bottom to nearly 60lbs. per square inch,) the core is strengthened by diametrical iron bars entering a little way into the brick-work. The outer cylinder is surrounded by iron rings piled one on the other and made tight by ramming in sand, and stays are placed in all directions from the rings to the sides of the pit.

Large pans and other circular works are moulded in the same way as cylinders, except that circular templets are used. The cores of water-pipes are turned upon an iron tube pierced full of holes, which is placed horizontally across two iron tressels with notches, and is kept in rotation by a winch handle at the end: a shaper board or scraper is fixed parallel with the axis. This arrangement is called a *founder's lathe.* The perforated tube is first wound round with haybands, then covered with loam, and the core is turned, dried, and blackwashed: the thickness is next laid on and blackwashed, after which the tube to be cast is moulded in sand. The thickness is then removed from the core, and the core is inserted in the mould, and supported therein by the two points at the extremities, and by *grains,* or two little plates of sheet-iron connected by a long central wire, the lengths of which may be seen by the bosses on the pipe, the metal being purposely made thicker to prevent the chance of leaking at those parts. In some cases, however, where pipes are cast in large quantities, they are moulded from wooden patterns in halves, so that it is only necessary to turn the core. The moulds for crooked pipes and branches are also frequently made in halves.

Many large works in brass are also moulded in loam. In some ornamental works, wax is employed for the thickness, and this is melted out before pouring the metal. Large bells are turned by means of wooden templets edged with metal, and shaped to the inner and outer contour of the core and thickness. The inscription and ornaments are either impressed within the cope, the clay of which is partially softened for the purpose, or the ornaments moulded in wax and fixed on the clay thickness before making the cope. In completing the apertures where the spindle passed, a dissected wooden pattern of the central stem and of the six *cannons* or ears by which the bell is slung is attached: these parts are moulded in soft loam, and the whole being dried and the iron ring for the clapper inserted, the whole is ready for the pouring pit. The heaviest bells are moulded within the pit.

Brass guns are moulded in loam, in the following manner:—A taper rod of wood much longer than the gun is wound round with soft rope, upon which the loam is put for making the rough casting model of the gun, which is turned to a templet, and the work is executed over a long fire to dry it as it proceeds. The model when dry is covered with a shell of loam about 3 inches thick, secured by iron bands, which is also dried. The taper bar is then driven out from its small end, the coil of rope is also pulled out, as well as every piece of the clay model. The parts for the cascabel and trunnions are worked separately on wooden models, and are then attached to the shell. Ornamental figures are modelled in wax and fixed on the clay mould before the shell is formed, and are afterwards melted out before casting. Six, eight, or more of these loam cases or shells are sunk perpendicularly into a pit at the mouth of the furnace, and the earth is carefully rammed round them; a vertical runner is made to each mould, to enter either at the bottom or not higher than the trunnion: the runners all terminate in the bottom of a long trough, at the further end of which is a square hole to receive the surplus metal. "In casting brass guns, tapping the furnace is rather a ceremony, and certainly an imposing sight: the middle and the end of the trough are each stopped by a shovel or gate held across the same; and the runners are stopped by long iron rods, there being a man to each. When all is pronounced to be *ready,* the stopper of the furnace is driven inwards with a long heavy bar, swung horizontally by two or three men, and the metal quickly fills the trough; on the word of command, "Number 1, draw," the metal flows into the first mould, and fills it quickly but quietly from the bottom; the mould being open at the top, no air can be accidentally enclosed. Numbers 2, 3, and 4 are successively ordered to draw. The first shovel is then removed from the great channel, and now the guns 5 to 8 or 10, as the case may be, are similarly poured and filled to the level of the trough; after which the last shovel is withdrawn, and the residue of the metal is allowed to run into the square bed or pit prepared for it. The flow of metal from the furnace is regulated by the tapping bar, the end of which is taper, and is thrust more or less into the mouth of the furnace as required: the trough and runners are thus kept entirely full, which is an important point in most cases of pouring, as it prevents a current of air being carried down by the metal. Large bells are poured much in the same manner, except that the runners are at the top, and the metal runs from the great channel through smaller ones to each sunk mould, the stoppers for which are successively drawn. For quantities of brass intermediate between the charge of an ordinary crucible, and such as require the reverberatory furnace, the large ladles or shanks of the iron-founder are used; the contents of 4 or 6 crucibles being poured into the shank as quickly as possible, and thence in one stream into the mould."

The furnace used for melting the iron for casting, is a blast or *cupola* furnace, although the cupola or dome leading to the chimney, from which it probably derives its name, is frequently omitted At the basement is a pedestal of brick-work 20 or 30 inches high, on which is erected a cast-iron cylinder from 5 to 8 feet high, and from 30 to 40 inches diameter: this is furnished with a lining of road-drift and other badly conducting substances, which contract its internal diameter to 18 or 24 inches. It is open at the top for the escape of flame, &c., and for the admission of the charge of pig-iron, waste or old metal, coke and lime, in proper proportions. The lime, which acts as a flux, is sometimes provided in the shape of chalk and oyster shells. The back of the furnace is provided with holes, one above the other, for the blast, which is urged by bellows. As the fluid metal collects at the bottom of the furnace, the blast pipe is removed to a higher hole and the lower one is stopped with sand. The front aperture, by which the melted metal is drawn off, is made sufficiently large to allow the fuel, slag, &c., to be rapidly raked out, as the intense heat renders this operation an arduous one. This opening is closed by a *guard-plate* fixed on by staples attached to the iron case of the furnace: in the centre of this plate is the tapping hole, which is closed during the melting with sand well rammed in.

For large castings several of these furnaces are worked side by side: but a single cupola has been made to contain upwards of 12 tons of melted iron.

The proportioning of the charge for the iron furnace requires much judgment: it always consists of two, and often of six kinds of new pig-iron mixed together, to which new iron and a small proportion of old cast-iron is usually added. For sound castings with a smooth face, as for ornamental works, the soft kinds of iron containing most carbon are used: these are more fusible and flow easily. In castings for machinery, the object is to obtain a strong, sound and tough iron. Between the extremes of 3 parts pig-iron to one of old, or 3 parts of old to 1 of pig-iron, various qualities may be selected; but this is a point which depends so much on the experience of the founder, that very little can be safely written on the subject.

When everything is ready for casting, the hole near the bottom of the cupola is tapped, and the contents let out into ladles, or, in large works, into channels leading directly to the moulds. One man will carry from 50 to 70 lbs. in a hand-ladle; or 3 to 5 men will carry from 2 to 4 cwt. in a double hand-ladle or *shank:* larger quantities, amounting to from 3 to 6 tons, are carried in the crane-ladle. These ladles are all coated with a thin layer of loam, and every time they are used are brushed over with black-wash and carefully dried. The hand-ladle has a handle 3 or 4 feet long, with a *crutch* or cross-piece at the end. The shank has a single handle on one side, and a handle with two branches on the other, measuring together 6 or 8 feet: the tilting is managed by the man or 2 men at the double handle. The crane-ladle is carried from the furnace to the mould, by the motions of the crane. The *bail* or handle is fixed by a bolt or guard, to prevent the ladle being overset, until it has reached its destination. Two long handles with forked branches are fitted by their square sockets upon the swivels or pivots of the crane-ladle, and secured by transverse keys; the guard is then removed, and then 2 men at the ladle, 2 others at the crane, and 1 to skim the dross from the lip of the ladle, are sufficient to manage 2 or 3 tons and upwards of fluid-iron. "When cast-iron is very hot the metal scintillates most beautifully, far more vividly than a mass of wrought-iron raised above the welding heat: as the metal cools the sparks become intermittent, and at last the metal is entirely quiet, excepting a multitude of lines vibrating in all directions, as if the surface were covered with thousands of wire-worms in great activity: this effect lessens until the metal solidifies. The softest iron shows most of this play of lines, and is said to *break* the best. The pouring of very large objects in open moulds, such as plates, beams, girders, &c. is a very beautiful and grand sight. The metal is led from the furnace, through a gutter lined with sand, into a large trough or sow, the end of which is closed with a shuttle: when the sow is full the shuttle is raised: this allows the metal to flow very quickly into the mould, but enables it to be kept back, should it be unnecessarily hot. The castings made in open moulds are generally covered up with sand as soon as the metal is set."

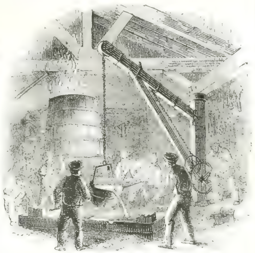

Fig. [illegible]. POURING.

The larger number of castings are in the horizontal position, but cylinders, pipes, shafts, &c., and works which are required to be particularly round are cast vertically. In this case all the precautions before explained, for giving the mould sufficient strength to resist the pressure of the fluid metal, must be adopted, but as soon as the metal is set this resistance must be removed from the inner surface, in order that the cylinder may shrink in cooling without restraint. Accordingly, a few hours after the casting all the diametrical iron-stays are knocked away by a vertical weight or monkey, and men descend by iron ladders into the cylinder to break down the brick core; but the heat is so intense, that they cannot remain above a minute or so at a time. The precaution is however quite necessary to prevent fracture, and even in small castings of hollow objects, it is desirable to break down the cores to prevent them from scoring or breaking.

When the castings are removed from the mould, the runners are broken off, and the loose sand scraped off with iron shovels, wire brushes, &c., and the seams are smoothed off with chisels and files. The skin or crust of castings made in sand moulds, is generally harder than that of loam castings. In some cases, as in the teeth of wheels, it is desirable to retain this hard sand crust on account of its greater durability. When it is to be removed, it is usual to pickle the works in dilute sulphuric acid, in a trough lined with lead, or to sprinkle the acid over them, and in a few days a thin crust is formed, which may be washed off with water, aided by slight friction. For pickling brass or gun-metal, dilute nitric acid is used.

The celebrated black iron trinkets commonly called Berlin ware, are successful examples of good castings on a small scale. This manufacture originated at the time of the commencement of the final struggle between Prussia and France under Napoleon. The country, impoverished by long and unsuccessful wars, was enabled to struggle with her oppressor chiefly by the patriotism of her sons, who yielded their services, and of her daughters, who sent their jewels and trinkets to the royal treasury. Those who made this sacrifice received in return rings, crosses, and other ornaments in cast-iron, which bore the inscription, *Ich gab Gold um Eisen*, "I gave gold for iron," and to the present day these articles are valued as heirlooms in the families of the donors. The foundry is at Berlin, and strangers are admitted to witness the operations. The castings are not confined to trinkets; busts, statuettes, bas-reliefs, &c. are cast with great delicacy and fineness of impression, as well as minute filagree ornaments. Such is the fineness and delicacy of the separate arabesques, rosettes, medallions, &c., of which the larger ornaments are composed, that it requires nearly 10,000 of them to make up a pound weight. The price increases in proportion to the fineness, and taking the price of grey iron from which these ornaments are made at 6*s.* per cwt., the value of the material is increased 1,100 times in the coarser articles, and 9,827 times in the finest. The excellence of these castings is said to be due both to the quality of the iron, and to the care bestowed on the moulds, which are formed of a very fine sand mixed with a small portion of clay. Professor Ehrenberg says that the iron employed is made from a bog-iron ore, and that the sand is a kind of tripoli also containing iron: both are entirely constituted of various kinds of animalcules, several of which are found both in the fossil and recent states in the neighbourhood of Berlin.

One of the most delicate and difficult operations connected with casting is the formation of specula for reflecting telescopes. This subject has of late years received some important improvements at the hands of the present noble President of the Royal Society, the details of which are so exceedingly interesting in a mechanical point of view, that we propose to give a tolerably full abstract of them.

In the year 1840, Lord Oxmantown (now Earl Rosse) communicated to the Royal Society of London "an account of experiments on the Reflecting Telescope," the results of which were, "that specula can be made to act effectively, cast of the finest speculum metal, in separate portions, retained in their positions by an alloy of zinc and copper, as easily wrought as common brass, and that they can be executed in this manner of any required size; that castings of the finest speculum metal can be executed of large dimensions, perfect, and not very liable to break; that machinery can be employed with the greatest advantage in grinding and polishing specula; that to obtain the finest polish, it is not necessary that the speculum should become warm, but that any temperature may be fixed upon and preserved uniform during the whole process; and that large specula can be polished as accurately as small ones, and be supported so as to be secured from flexure."

To avoid the brittleness of the best speculum metal, it had hitherto been found necessary as the dimensions were increased to use an increased proportion of copper, so that the alloy was inferior in brilliancy, yellower, and much more liable to tarnish. In polishing large surfaces there were great and peculiar difficulties, all the defects having a tendency to augment rapidly with the size, and proportionately to impair the defining power.

Tin and copper, the materials employed by Newton in the first reflecting telescope, are preferable to any other; the best proportions being 4 atoms of copper to 1 of tin, or 126.4 copper to 58.9 of tin. This alloy, as well as every other speculum metal examined by the author, is porous, and the porosity can be detected with a simple Coddington's microscope.

The refined copper as it is procured from the merchant, and the best block tin are the materials. The difficulties experienced by Herschel and others in safely casting and polishing a very large speculum were proposed by Lord Rosse to be got rid of by uniting several castings into one reflecting surface, and as the best means of effecting that, to solder them upon an alloy of 1 zinc and 2.75 copper, which expands and contracts in the same proportion as speculum metal. To test this a bar was cast of speculum metal, 15 inches long and 1¼ inch square. Similar bars ¾ inch thick were cast of the alloys to be tried, containing a little more or less zinc than the proportions here given. A piece of brass consisting of 2.75 copper to 1 zinc was also cast and soldered to the bar of speculum metal, Fig. 544, where A B is speculum metal, C D brass, and E F the bar of alloy, with a small excavation in the lower end fitted by grinding, so as to rest steadily on the hemispherical disk G. A thin slip of brass was also soldered at the upper end of the bar of speculum metal, and the two bars made to fit neatly there, so that when brought together, a very fine line could be drawn across them with scarcely any troublesome parallax at the joint; the whole was then immersed almost to the top in a tin vessel of water of the temperature of the atmosphere, and that vessel placed in another much larger, also containing water. Pieces of ice were then dropped into the outer vessel, so that the temperature of the whole was evenly and gradually brought down to nearly 32°, and a straight line as fine as possible was then drawn across both bars, and examined with a microscope to ascertain that it was perfect. The temperature was then gradually raised by pouring hot water into the outer vessel, to nearly 212°, and the line was again examined with a

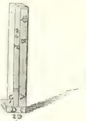

Fig 544.

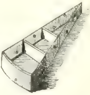

Fig 545.

microscope, and when the alloy had been made by mixing 2.74 copper with 1 of zinc, and the loss in melting amounted to $\frac{1}{180}$th of the whole, the continuity of the line was not broken in that range of temperature; according, however, as the proportion of the zinc was more or less, the expansion of the brass bar was greater or less than that of speculum metal.

Speculum metal and brass cannot be soldered together by the ordinary methods, except on a very small scale. But they may be soldered by first fitting the brass and speculum metal nicely together by fitting or grinding. The brass is then to be tinned and suffered to cool. Scrape the surface of the speculum metal lightly all over with a sharp chisel; then place the two surfaces in contact, and a slight pressure may be applied after the fusion of the tin, and continued until it is again solid. The temperature should then be gradually raised till the tin melts; and then, but not till then, resin is applied in fusion, and also a little melted tin. If resin or tin be applied in the solid state, owing to their rapid absorption of heat in becoming fluid, they will crack the speculum metal. The surfaces may be slightly separated, so as to ascertain that the speculum metal is tinned all over, which will be the case when the temperature reaches 400°. The whole must then be suffered to cool gradually.

In casting the alloy of zinc and copper some precautions are necessary to prevent so much of the zinc being volatilized, and thus producing speculum metal of varying and uncertain composition. Charcoal in fine powder must be spread over the surface of the metal in the crucible in a layer 2 inches thick, and occasionally renewed by throwing it in, folded up in paper. With this precaution the loss will be about $\frac{1}{180}$th, and almost exactly the same each casting.

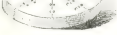

Fig. 546.

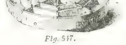

Fig. 547.

Fig. 548.

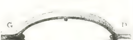

Fig. 549.

The proportions of zinc and copper having been determined, the brass-work was first cast. The figures will show how the materials were disposed of. Fig. 545 represents one-eighth part of the whole seen in the reverse, a single casting. Fig. 547, the whole speculum also seen in the reverse; and Fig. 546 seen on the opposite side, previous to the soldering on of the plates of speculum metal; Fig. 548, the speculum complete, faced with 16 plates of speculum metal. The whole depth of the brass-work was $5\frac{1}{2}$ inches, and weighed about 450 lbs. The sides I B, Fig. 545, were made square and true, and then tinned, and the whole bolted together with iron bolts. The temperature was then raised till the tin was in fusion, and the bolts tightened to the utmost, so as to make close joints. In this state the speculum was turned, plated with speculum metal and polished. A flexure was, however, observed in this speculum, and it was supposed that the solder was not everywhere perfect. The plates of speculum metal were therefore taken off, and the joints secured by bedding the whole mass of brass-work in casting-sand; over it there were about 3 inches of sand. The sand was then removed from the centre, so as to expose a circular surface about $1\frac{1}{2}$ inch diameter, and about 45 lbs. of very hot melted brass, in the same proportions as the brass speculum, were poured upon it in a continuous stream from a height of about 10 inches; the sand having been so arranged that after the melted brass had reached the depth of 2 inches, the remainder continued to flow off. The melted brass soon fused the cold metal, and perfectly united with it at the place where it was poured. This was repeated in 34 different places, marked by dots in the figures. It was also tried in the places marked *c c*, but failed. When the redundant brass had been removed with a saw, and the surface made smooth, a slight hair crack was perceptible at the boundary of the fused metal, proceeding no doubt from expansion and contraction after the brass had ceased to be fluid, but before it had become ductile. This process is used by the brass-founder in stopping holes in defective castings; he calls it *burning*. To secure the joint at *c c* holes about $1\frac{1}{2}$ inch diameter were bored completely through at *c*, and the intermediate brass chiselled out. They were then filled with melted brass, which was easily done by imbedding the whole in sand; clearing the sand completely out of the spaces, and pouring the brass into each through a hole in a flat surface of sand packed in a small flask; when the brass cooled, the contraction was sufficient to draw the joint firmly together. As any further yielding in the joints was now judged to be impossible, the speculum was again placed on the lathe and turned to a radius of 54 feet, and new plates of speculum metal prepared for it.

Although none of these plates exceeded 9 inches square, much difficulty was experienced in casting them. When cast in sand they were seldom free from flaws, and although cooled very slowly were extremely brittle, sometimes flying in pieces the moment they were touched, and generally breaking in attempting to heat them for soldering. As the broken pieces of these plates did not fit each other, the metal had evidently been in a state of tension, owing to the edges of the plates becoming solid sooner than the centre. If it were possible to abstract the heat rapidly and equally from the lower surface of a fluid disk of speculum metal, so that it should solidify from the bottom upwards in thin laminæ, the surface being the last to solidify, a perfect casting would be obtained; for the particles in that case being deposited in such a way as to fill up the interstices, there would be no flaws; but the temperature being uniform in a horizontal direction, and in the vertical varying in regular gradation from the lower surface to the upper, there would be no strain

This adjustment of temperature was tried in two ways; the one by cooling the lower surface of a mould containing the liquid speculum metal, while the heat of the upper remained undiminished; the other by constructing the mould itself, so that the lower surface should absorb the heat rapidly, and the upper retain it. Both were tried; the first by making the mould of cast-iron in which the metal was fused, and then exposing its lower surface to the action of a jet of cold water. The result was favourable, but the mould frequently cracked and spoiled the casting. By the second plan the bottom of the mould was made of iron and the sides of sand: when an iron plate was used, bubbles of air were often entangled between it and the speculum metal, producing cavities which had to be ground out: the iron disk was therefore replaced by one made of pieces of hoop-iron, placed side by side with their edges up, tightly packed in an iron frame; the edges were brought to a smooth surface of the proper curve either by the file or lathe. A porous metallic surface was thus formed, through which the air could pass freely. This plan was so successful, that of 16 plates cast for the three-feet speculum, not one was defective. The disk of hoop-iron must be as thick as the speculum to be cast upon it, so as to cool with sufficient rapidity: it requires to be warm (212°), so that no moisture be deposited on it from the sand. The metal should enter the mould by the side almost instantaneously. The temperature of the metal is best ascertained by stirring it with a wooden pole occasionally after it has become fluid; when the carbon of the pole reduces the oxide on the surface of the metal, and renders it brilliant, like mercury, the heat is sufficient. When the metal has become solid in the ingate or hole through which it enters the mould, the plate is to be removed quickly to an oven heated a little below redness, to remain till cold, which where the plates are 9 inches in diameter, should be 3 or 4 days at least.

The metal which had filled the ingates having been separated from the plates by a file, they were fitted to the brass speculum by grinding each separately by hand upon it till brought to the same curve. The surface of the brass speculum was then scraped and tinned, and when cold all the resin was removed by washing it with turpentine and then with soap and water. The lower surfaces of the plates which fitted the brass speculum were scraped with broad flat chisels of hard steel, and then arranged in their places on the brass speculum placed in an oven arranged like a sand-bath, so as to be heated entirely by hot air. In about 8 hours the tin on the speculum was fused, and then melted resin was poured in between the plates; fused tin was also afterwards applied in the same manner, and the plates moved a little backwards and forwards. As soon as from the aspect of the edges of the plates it was certain that the tin was acting on the speculum metal, the fire was almost all withdrawn, and the temperature not suffered to rise. The joints of the plates were now made straight, and kept open about $\frac{1}{20}$ inch by chips of wood: the whole was then suffered to cool gradually, and in five days it was ready to be ground.

The perfect union of the plates with the brass speculum, depends upon the fact that if a plate of speculum metal, scraped as directed, be laid upon a clean surface of tinned brass, and the temperature raised a little beyond the fusing point of tin, and then melted resin and tin applied, the plate of speculum metal will be tinned all over and the union be perfect. But if the resin be applied at the beginning of the process, and therefore exposed for hours to an increasing temperature, the resin will become decomposed and prevent the success of the operation.

Perfect plates of speculum metal of moderate dimensions having been cast, a trial was made on a larger scale, and a perfect disk of fine speculum metal 20 inches in diameter was obtained, and recently, so large a disk as 3 feet was cast perfect and finished without accident. The disk was about $3\frac{3}{4}$ inches thick, and weighed about 13 cwt. The metal for it was fused in two cast-iron crucibles. It is curious that iron crucibles cast in the usual way with the mouth down are generally defective, and the fused speculum metal will escape through minute pores in the crucible not visible externally, just as mercury passes through the sap vessels of wood But when crucibles are cast with the mouth up there is no such defect. Lord Rosse cast one which held 15 cwt., in which the speculum metal was made; but as two crucibles of half the size were more manageable with less machinery, they were used in casting the speculum: they were raised from the furnaces by proper tackling, and placed in iron swing frames, so contrived that each crucible of metal could be thrown almost instantaneously into the mould. The fuel used is wood or peat, which is less injurious than coke upon the crucibles. The mould was made in the same manner as in casting the plates, differing from it merely in shape and dimensions: it was what founders call an open one. The disk of hoop-iron was made circular, $3\frac{1}{2}$ feet in diameter, $3\frac{1}{2}$ inches thick, and turned upon a lathe to a radius of 54 feet. The speculum was cast with a groove round the edge, so that it might be securely embraced by a circular clamp tightened upon it with screw-bolts, to which the proper tackling could be hooked when it was required to move it. When the metal had become solid, but was still red-hot, a strong hoop somewhat larger than the diameter of the speculum was placed upon it; to this hoop a chain from a windlass passing through the annealing oven had been previously attached, and by the action of the windlass the speculum was drawn into the hot oven, and every opening closed: in about a fortnight it was cool, and was found to be free from blemish.

On comparing the speculum thus formed at a single casting, with that formed by combining a number of small castings, no appreciable difference was found as to defining power; both were free from flexure in the different positions of the instrument, and defined equally well when polished with equal success. With a single lens of $\frac{1}{4}$ inch focus, giving a power of about 1,300, they have both shown satisfactorily the dots on the dial plate of a watch more distinctly than a very good refractor with a much lower power.

Before the speculum is polished, it is worked to a spherical figure by *grinding*, a process in which the mutual attrition of the speculum, and a mass of nearly equal size of some hard substance, eventually produces a figure nearly spherical, notwithstanding the irregularities of the surfaces of either or both at the commencement of the operation. But although the accuracy usually attained is so great, that mechanical means fail to detect any deviation from the proper figure, yet by optical means, in fact by trial in a telescope, the defects are at once apparent, and among a variety of specula, examples may be found of every grade of defining power, from the speculum which is almost perfect to that which does not define at all. These differences arise from variations in the extent or relative velocities of the motions by which the necessary friction is produced; alterations of temperature; or some accidental pressure during the process. It was always supposed that specula could not be polished successfully except by the hand; but so long back as 1828, Earl Rosse published a sketch of a machine for grinding and polishing specula. This machine, enlarged so as to be capable of working a speculum 3 feet diameter, and otherwise improved, was used on the present and many other occasions, and in working large surfaces a degree of precision is attained which by the hand is impossible. The machine in its present state is shown in Fig. 550, where S is a shaft connected with a steam-engine, (one horse-power is sufficient;) E an eccentric, adjustable by a screw-bolt to give any length of stroke from 0 to 18 inches; J a joint; G a guide; C a cistern of water in which the speculum revolves; E′ another eccentric, adjustable like the first from 0 to 18 inches. The bar *g* E′ passes through a slit, and therefore the pin at E′ necessarily turns on its axis in the same time as the eccentric; S P is the speculum in its box, immersed in water to within 1 inch of its surface, and P the polisher, which is of cast-iron and weighs about 2½ cwt.; D is a disc of wood connected with the polisher by strings hooked to it in 6 places, each two-thirds of the radius from the centre. At D is a swivel and hook, to which a rope is attached connecting the whole with the lever L, so that the polisher presses upon the speculum with a force equal to the difference between its own weight and that of the counterpoise W. For a speculum 3 feet diameter, the counterpoise is made 10lbs. lighter than the polisher. The bar *g* E′ fits the polisher nicely but not tightly, so that the polisher turns freely round, usually about once for every 15 or 20 revolutions of the speculum, and it is prevented by 4 guards from accidentally touching the speculum, and from pressing upon the polisher, by the two guides through which its extremities pass. In Fig. 549 this bar is shown on a larger scale. The wheel E makes, when polishing a 3-feet speculum, 16 revolutions per minute; to polish a smaller speculum the velocity is increased by changing the pulley on the shaft S. The machine is in a room at the bottom of a high tower, and doors can be opened in the successive floors, so that a dial-plate placed perpendicularly over the speculum can be examined at any moment. The dial-plate is attached to a mast, so as to be much higher than the tower and about 90 feet from the speculum; and a small flat metal eye-piece with its proper adjustments completes the arrangements for a Newtonian telescope. This simple contrivance greatly facilitated the progress of the experiments. All the motions of the machine were produced by bands 3 inches wide instead of cog-wheels, the former being preferred, because if any part of the machinery should become fast the band falls off or breaks, and no mischief is done.

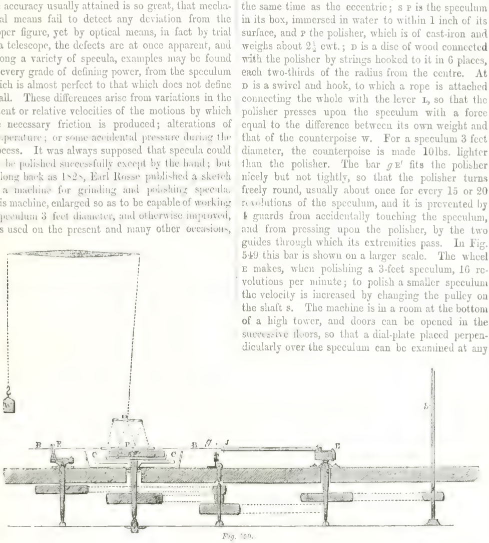

Fig. 550.

The first serious difficulty in polishing specula of large size was, that when the layer of pitch used as a bed for the polishing powder was thin, as it must be to produce a good figure, however accurately it fitted the speculum at first it soon ceased to do so, and the polishing did not proceed properly. During the operation of polishing, the abraded matter, mixed with the polishing powder, is in part taken up by the pitch, but not equally over the whole surface. As pitch is not sensibly elastic with a moderate pressure, wherever most is taken up there the surface will be most prominent, and the figure of the polisher destroyed unless the pitch can spread laterally. It occurred to his Lordship that by grooving the layer of pitch provision might be made for its lateral expansion, without increasing the thickness of the layer, which is most objectionable. The experiment was tried by reducing the thickness of pitch one half, and making furrows in it by means of a hot iron quite down to the metallic plate; the furrows were 2 inches apart, and there were 2 sets at right angles to each other. The result was that the defining power of the speculum was immediately much improved. But the difficulty of keeping the furrows open, of preserving the figure of the polisher, and of reducing the thickness of the pitch to a minimum, which was a great object, still existed; but all defects were remedied by dividing the iron disc itself instead of the pitch: this was accordingly done by turning circular grooves in it $\frac{3}{8}$ inch deep and $\frac{1}{4}$ inch wide, and also grooves at right angles $1\frac{1}{4}$ inch apart, $\frac{1}{4}$ inch wide, and $\frac{1}{2}$ inch deep. Fig. 552. The speculum was truly ground with the polisher first, and then the layer of pitch or resinous composition applied, the grooves remaining empty. The improvement which followed this simple device was decided; for the divided 3-feet speculum defined better with a power of 1,200 than it had done before with a power of 300. The two conditions necessary to success, are that the polisher should fit the speculum exactly during the whole process, and that the resinous surface in contact with the speculum should be as hard as possible consistent with its admitting the polishing powder to imbed itself in it. A mixture of common resin and turpentine was found preferable to pitch, on account of the gritty particles so common in the latter. It is desirable also to use the resinous composition of two different degrees of hardness, so as to form two very thin strata, the outer one being the harder. Thus the surface in contact with the speculum can be made as hard as necessary, while the thin subjacent layer of soft resin expands laterally so as to preserve the figure of the polisher. The composition is prepared by melting common resin, and when nearly boiling adding about $\frac{1}{5}$ of its weight of spirit of turpentine: when the mixture has been incorporated by stirring, a piece of cold iron is immersed in it, and then placed for some minutes in a vessel of water at the temperature of 55°; if then a moderate pressure of the nail makes a decided impression without splintering, it is of a proper hardness for the first layer on the polisher, and only requires to be strained through canvass. For the second layer it is mixed with $\frac{1}{4}$ of wheat flour, which by increasing its tenacity and diminishing its adhesiveness prevents the common fault so much complained of, viz. the separation of minute particles of pitch from the polisher. It is to be boiled till the water of the flour has been expelled, and the mixture becomes clear, and the boiling further continued till some of the turpentine has been driven off, and the mixture has become so hard that at 55° a very strong pressure of the nail makes but a slight impression. An equal weight of resin is then added to it, when it will be hard enough to produce a very true surface, and yet soft enough to allow the particles of polishing powder to become imbedded. When the resinous mixture is remelted, the vessel is suspended to the beam of a scale, and the heat applied so gradually as not to drive off any of the turpentine, which is immediately perceptible by the disturbance of the equilibrium. To apply the resin the polisher is first heated to about 180°, and the soft mixture laid on with a large flat brush to about the thickness of $\frac{1}{30}$th or $\frac{1}{25}$th of an inch. It is then suffered to cool to about 100°, and the hard mixture is applied in the same way, and to about the same thickness. When the temperature has sunk to 80°, the polisher is placed on the speculum, previously covered with peroxide of iron and water, of about the consistence of thin cream. The speculum is made to revolve in a cistern of water, c Fig. 550, maintained at the constant temperature of 55°, and the hardness of the resinous composition is adjusted to suit this temperature as above explained. When the polisher is first applied at 80°, while the speculum is at 55°, there is no danger of fracture, because the layer of resin retards the transmission of heat; but in grinding, where there is no resin, such a difference would lead to the fracture of the speculum. In grinding the 3-feet speculum formed in separate pieces, the iron plate happened to have been washed with warm water, and though but little warmer than the speculum, the moment it was put on several of the plates cracked; these of course admitted of being replaced. Had it been the other speculum in one piece, it would of course have been destroyed.

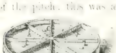

Fig. 551.

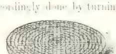

Fig. 552.

The polishing powder must be prepared by precipitation with water of ammonia from a pure dilute solution of sulphate of iron. The precipitate is to be washed, pressed in a screw-press till nearly dry, and then exposed to a heat, which in the dark appears a dull low red. The sulphate of iron must be pure, the ammonia in excess, and the heat not greater than that indicated. The colour of the powder will be a bright crimson inclining to yellow.

We have thus abstracted from Earl Rosse's most interesting paper the principal mechanical details which he has found successful in the casting, grinding, and polishing of large specula. There are other details connected with the figure of the specula, the method of mounting them, and the astronomical results obtained from their use in telescopes, which do not belong to this article.

CASTOR, a brown viscid substance, secreted by castors or beavers, and formerly much used in medicine in nervous and spasmodic diseases. At the present time not only are the virtues of this substance considered very equivocal; but the uncertain composition and quality of that offered for sale afford good reason for allowing it to fall into disuse.

CASTOR OIL. An oil obtained by boiling in water or by crushing in a press the seeds of the *Ricinus communis* or *Palma Christi*, an annual plant growing in tropical countries. This plant is extremely variable in size, has large vine-shaped leaves, green spikes of flowers, and rough capsules containing ovate shining black seeds spotted with grey. As cultivated in this country, the Palma Christi is an annual three or four feet high; in Sicily it is a woody and long-lived tree-shrub about the size of our common alder; in Spain and in different parts of India, it attains a larger size, and becomes a considerable tree. The seeds yield a pale fixed oil, nauseous and slightly acrid. When this oil is obtained by boiling, it is deeper coloured and more acrid, and also more liable to become rancid, but is also generally more active than the pale-coloured oil. Some of the oil now sold is absolutely without colour or taste, and appears to have undergone a decolouring process, but in this state it is frequently almost inactive; so that oil of a pale straw-colour having a slight degree of taste and smell is preferred.

Castor oil was formerly expressed with heat, but this and the mode of boiling the seeds in water is now seldom adopted; *cold-drawn* castor oil being the favourite form of this medicine. Some medical writers consider cold-drawn oil as more active than that obtained by boiling, while others affirm that the latter is more active than the former. This medicine is well known as a mild laxative, which can be safely employed in all cases except those in which it is dangerous to excite vomiting, an effect sometimes produced by it. Castor oil congeals at about 0°; exposed to air it gradually becomes rancid, and very thick and viscid; it dissolves in absolute alcohol and ether. Its sp. gr. is about .960. When treated with a little nitric acid, it is converted into a substance resembling hard butter.

CASTORS, small wheels attached to the legs of furniture, to allow of its being easily moved about. Harcourt's castors are shown in Fig. 554, the upper or socket part being in section. Round the central pin is fixed a guide-plate, so as to revolve with it. This plate contains circular holes, in each of which is a small sphere which rolls as it is carried round with the plate. Fig. 553 is a plan of the guide-plate, which may contain three or more apertures for the antifriction rollers; and these may be spherical as *s s* or cylindrical as *c*. The use of these antifriction rollers is to remove the strain and pressure on the central pin.

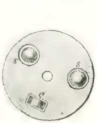

Fig. 553.

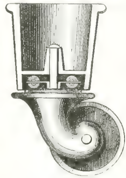

Fig 554.

CATECHU, see Leather, Sec. ii.

CATENARY, the curve in which a perfectly flexible cord or chain (Latin *catena*, a chain) hangs when it is suspended by two points that are not in the same vertical line. "All catenaries are similar curves; that is to say, let there be any number of such curves formed by chains of different lengths, then each of them will be a picture, on a reduced or enlarged scale, of some portion of the longest." The properties of the catenary are of great importance from the general use of this curve in suspension bridges. "The curve, however, of a chain supporting the roadway of a bridge is not strictly a catenary. In the catenary the weight is supposed to be distributed so that each equal length sustains an equal portion of it. Now the weight of the roadway of a bridge is not so distributed on the chains. The suspending rods are, indeed, placed along it at equal distances from one another, but the lengths of the portions of the curve included between these are different; those about the lowest points of the chain only being equal to the included parts of the roadway, whilst those near the extremities are greater. Hence, therefore, the chains used in supporting the roadway of a bridge do not assume strictly the form of the catenary. Were the chain without weight, the pressure of the roadway upon it would, indeed, cause it to assume the form of the parabola. In reality it is a curve intermediate between the catenary and parabola, partaking of the properties of both."[1]

A catenarian curve is sometimes adopted for arches and vaults. A practical instance of the equilibrium of the catenary is mentioned by the writer of the article Bridge in the Encyclopædia Metropolitana. "A scientific gentleman of Birmingham having occasion for a close factory for the manufacture of the article called Roman vitriol, set out a piece of ground to be covered by a brick arch of considerable length, the chord of which was 18 or 20 feet, and its versed sine about 12. He suspended a chain against a wall, the points of suspension being equal to the chord of his intended arch, and its depth equal to its versed sine. From a line traced from the chain his carpenters made a centre, over which the bricklayers turned a single arch of 9 inches only in thickness, without spandrels or other external support, its extrados being a curve parallel to its intrados at a distance of only 9 inches. It is a perfectly sound and beautiful piece of construction. During an absence from home he desired another to be built like it. The self-sufficient workman varied the curve

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(1) Moseley, "Mechanics applied to the Arts."

to give it more room in its haunches, or a more graceful curve, and on striking the centre it fell."

CATGUT, a name given (inappropriately as it would appear[1]) to cords made of the twisted intestines of the sheep. When the intestines are removed from the body of the animal, they are freed from feculent matter and adhering fat, and washed in a tub of water. The small ends of the intestines are then tied together, and placed on the edge of the tub, while the great bulk is left during two days to soak in the water, which is frequently changed. In this way the peritoneal and mucous membranes become loosened. The bundle of intestines is then laid upon a sloping board overhanging the tub, Fig. 555, and the man with a square steel edge scrapes the surface, and removes the external membrane in breadths of about half the circumference of the intestine. The French term this substance *filandre*, and the process *filer*. It cannot be removed by beginning at the large end. This filandre is used as thread to sew intestines, and also to make the cords of rackets and battledores. The scraped intestines are steeped during one night in clean water, and next day are again scraped with a rounded edge. This is called *curing*. The large ends of the intestines are cut off, salted, and stored in covered tubs for the purpose of being sold to the pork sausage-makers. The intestines are again steeped for a night in fresh water, and the next day are treated with an alkaline mixture formed by adding 4 ounces of potash, the same quantity of pearlash, to 3 or 4 gallons of water. The membranes are then distributed to a number of women, each of whom stands before two basins or pans containing the alkaline solution, Fig. 556; and each woman draws the intestines through an open brass thimble, pressing them against the edge for the purpose of smoothing and equalizing them. In this way the membranes are passed from one basin to the other several times. They are next sorted into different sizes, according to the purposes for which they are intended.

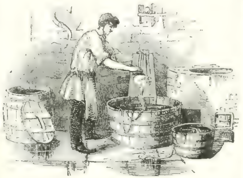
Fig. 555. SCRAPING.

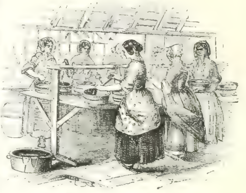
Fig. 556. PASSING THROUGH THE THIMBLE.

For making *whip-cord*, the intestines, prepared as above, are sewed together by means of the filandre, each junction being cut aslant, in order to make it smoother and stronger. A number of these cords are then put into a wooden frame, the two uprights of which are furnished with a quantity of holes containing pegs for securing the ends of the gut, and for passing the lengths round. The spinner attaches the end of one of the cords to the hook of a little whirling apparatus, (similar to the *whirl* of the rope-maker, only smaller,) which he causes to rotate rapidly by turning a handle: this puts twist into the gut, and somewhat diminishes its length. He secures the twist by pegging the cord into the frame, and then proceeds to twist another cord. When all the cords have been treated in this way, and other frames of cords similarly twisted, they are all piled up horizontally in a small close chamber, lined with lead, where they are subjected to the action of the fumes of burning sulphur. The manufacturer calls this *bleaching;* the effect, however, is not to whiten the cord, for that is produced by previous manipulations in alkaline leys, &c.; the real effect seems to be to destroy any animal matter that might still be attached to the membrane, and occasion putrefactive fermentation. Certain it is that, without sulphuring,

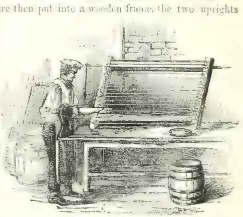
Fig. 557. TWISTING.

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[1] A writer in the Gentleman's Magazine for June 1818, speaking of the origin of the "Signs of Inns, &c." refers to the *Cat and Fiddle*, *Cat and Bagpipes*, and similar objects collocated without any apparent reason. He says —"Between the Cat and Fiddle there may, indeed, appear some connexion, as the entrails of the one are supposed to furnish the strings of the other; or the sign might originate in the ambiguity of the word *Kit*, at once the abbreviation of *Kitten* and a *small violin*."

the cords are liable to an unpleasant odour, and even to become mouldy. After the sulphuring, the whipcord may be dyed black with common ink, or red with red-ink, which the sulphurous acid changes to pink, or green with a green dye which the colour-maker sells for the purpose. The membrane takes the dye readily. The twist being completed, the cords are nicely smoothed, and are then placed for an hour or so in a hot room, where the heat, probably 180° or 200°, fixes and consolidates them: they are lastly cut off the frames and twisted up into coils for sale.

Hatters' cords for bowstrings, used in the curious operation of *bowing*, [see HAT,] are made of the longest and largest intestines of sheep, and after being properly cleaned and smoothed with the alkaline iey, they are twisted in lengths, 4, 6, 8, 10, or 12 together, according to the intended size of the cord, which is usually about 12 feet long. This cord must be free from lumps and knots, and when half dry it must be sulphured twice, and, after each operation, well stretched, twisted, and smoothed, and it is finally dried in a state of tension. The object of sulphuring cannot in this instance be to bleach, for colour is no object; some of these cords being dyed black, others a dingy red, and others left of their natural colour.

Clockmakers' cord must be very thin, strong, and durable, for which purpose it is made from very small intestines, or from intestines slit up in the direction of their length by a couple of razor-blades fitted into a ball of wood which serves as a guide. The wet gut, being drawn over the ball, is divided, and the two sections, properly directed by the workman, fall into a basin beneath. This operation is one of considerable delicacy, but when performed well, the gut is divided into strips of perfect regularity with great rapidity. A number of these strips are twisted together and treated as before.

The French prepare a very strong cord from the gut of the horse, ass, or mule, for driving machinery. The gut, having been scraped, is divided into four equal parts, by skilfully drawing it over a fixed knob containing four sharp edges, or two semicircular blades, arranged at right angles. 4, 6, or 8 of these strips are tied at the ends with packthread, then twisted together, and polished with dogskin.

The strings for *harps*, *guitars*, and the instruments of the *violin* family, require the best attention of the cat-gut maker. The first scraping is performed with great care. A little alum is added to the alkaline leys, which are made progressively stronger every day for four or five days, till the membranes are well bleached and swollen. They are then passed several times through the thimble, after which they are spun, and sulphured, and are lastly polished by friction between horse-hair cords, and dried in the hot room.

The Italians make much better musical strings than the English. Otto, in his "Treatise on the Violin," says:—"The best strings which have come under my observation are those from Milan, which are sold under the name of *Roman strings*; they are sold to be had at almost every music-shop. I shall point out the signs by which the best strings may be distinguished, as there are some imitations of them manufactured at Neukirch, in Voigtland, in Bohemia, and in the Tyrol which are sold for Italian. The Milanese strings are as clear and transparent as glass. The third string should be equally clear as the first. They must by no means feel smooth to the touch, for they are not ground or polished off by any process, as all other manufactured strings are. If a good string be held by one end in the finger and opened out, it will recoil to its former position like a watch-spring. Every string when stretched on the instrument should look like a thin strip of glass on the finger-board: those which are of a dull and opaque appearance are useless. The Milanese strings are also distinguished by each separate one being tied twice with red silk: which, however, the Neukirch string-makers have imitated. Their elasticity is after all the best criterion, as no other strings which I have tried have that strength and elasticity for which the Milanese are so much esteemed."

The chief fault of the English compared with the Italian strings is weakness; whence it is difficult to bring the smaller ones required for the higher notes to concert pitch, maintaining at the same time in their form and construction that tenuity or smallness of diameter which is required to produce a brilliant and clear tone. The frequent fracture of such strings is a source of constant inconvenience and expense.

"It is well known to physiologists that the membranes of lean animals are far more tough than those of animals that are fat or in high condition; and there is no reason to doubt that the superiority of the Italian strings arises from the state of the sheep in that country. In London, where no lean animals are slaughtered, and where, indeed, an extravagant and useless degree of fattening, at least for the purpose of food, is induced on sheep in particular, it is easy to comprehend why their membranes can never afford a material of the requisite tenacity. It is less easy to suggest an adequate remedy; but a knowledge of the general principle may at least serve the purpose of diminishing the evil and improving the manufacture, by inducing the manufacturers to choose in the market the offal of such carcases as appear least overwhelmed with exuberant fat. It is probable that such a manufacture might be advantageously established in those parts of the country where the fashion has not, as in London, led to the use of meat so far overfed; and it is equally likely that in the choice of sheep for this purpose, advantage would arise from using the Welsh, the Highland, or the South Down breeds, in preference to those which, like the Lincoln, are prone to excessive accumulations of fat. It is equally probable that sheep dying of some of the diseases accompanied by emaciation would be peculiarly adapted to this purpose."[1]

The engravings which illustrate this article were made from sketches taken at a cat-gut manufacturer's in Sharpe's Alley, London. The manufacturer per-

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(1) Dr MacCulloch, in the "Quarterly Journal of Science, &c." 1821.

mitted the Editor to inspect the various processes above described, but refused to answer any questions which were put to him, or to allow of a second visit. We have, however, corrected our sketch from the excellent article, BOYAUDERIE, contained in M. Laboulaye's "Dictionnaire des Arts et Manufactures," Paris, 1845, and have also obtained some additional information therefrom.

There is a considerable demand for untwisted gut on the part of the sausage-maker, the druggist, the confectioner, and all those trades where clean dry membrane is required. For these purposes, the intestines are prepared in the following manner:—1. A length of gut is taken from the tub in which the fresh intestines are kept, and removed to a trough containing water. The small end of the gut is tied in a knot to a staple fixed to the end of a bar of wood rising up near the trough. The man then takes a length of a few feet in his left hand, and pulling it tight, scrapes it with a fleshing-knife, by which means he removes the peritoneal and fatty membranes from this portion. This being done, he unties the knot, and makes another near the place which separates the scraped from the unscraped portion; then, taking up another length, he scrapes as before. Any portion of the gut which is torn or rent, as often happens from the carelessness of the butcher, is cut off, and thrown aside. The fat which has been scraped off is washed and dried, and sold to the soap-manufacturer. 2. The scraped intestines are thrown into a vessel half-full of water. Taking up one of the ends, the man inserts his fingers into it, and presses his thumb on the outside: then with the other hand he draws the gut down, and dips it into the water, at the same time spreading his fingers to enlarge the opening. In this way, by advancing his fingers, drawing down the gut, and dipping into the water, the gut is quickly turned inside out. When a number of intestines have been thus prepared, they are tied together by the ends. 3. In this state they are left to ferment from 5 to 8 days, in winter, and from 2 to 3 in summer. The putrefactive process is known to be sufficiently advanced by the bursting of bubbles of gas on the surface of the water. In summer, the fermentation is liable to proceed too rapidly, in which case it is checked by throwing a glassful of vinegar into the tub. During this process, the putrid odour which is diffused all around is dreadful. 4. The mucous membrane, which has been loosened by this fermentation, can now be easily removed. The intestines are transferred to a tub two-thirds full of water, and a woman draws each gut between her hands, pressing it firmly against her nails, or against a blunt edge. This removes the mucous membrane; but a portion of the peritoneal membrane is still left, which is removed by a further process of putrefaction. 5. For this purpose, the intestines are thrown into tubs full of water, which is changed once or twice a-day, stirring them about each time. They are then left for two or three days before the water is removed. The water is at first in a state of ferment, and very putrid; an iridescent pellicle forms on its surface, and bubbles of gas frequently escape: the water at length becomes clearer, and the intestines are then taken out and blown. 6. This operation is performed by the men who scraped the guts: each man puts on a leather apron, and places his knife on the tub, so that its edge may be opposite to him, so as to be always ready when wanted. He holds in his mouth a hollow reed, about six inches long, which he inserts into one extremity of a gut, and distends it with air. He then withdraws the tube, and ties the end of the gut with thread: he then blows at the other end, which he secures in like manner. If the gut contain a small hole, it is discovered by passing the gut through water, with slight pressure; the air bubbling out shows where the hole is: this is made tight by pinching the membrane, and passing a ligature round it. If the gut is torn, it is tied above and below the rent. When the intestines are inflated, they are conveyed in osier baskets to the drying-ground. 7. The drying-ground is provided with long frames of wood, on which the blown membranes are spread, so as not to touch each other. If they have been properly cleaned, they will become perfectly dry in about two days; if not well cleaned, they scarcely become dry in five. In rainy weather they are put under shelter in sheds or lofts. They must also be protected from wind and dew and from the hot sun. 8. When dry, they are taken into a sort of damp cellar, where women cut off the ligatures, as also those portions of gut near the ligatures which have not been blown. The membranes are then pressed together to expel the air, and are, 9thly, made up into bundles, and left until sufficiently moist for sulphuring, or they may be made moist by sprinkling with water. 10. They are then hung up in loose bundles in a close room, and exposed for some hours to the fumes of ignited sulphur. Lastly, they are folded up in bundles, and packed in sacks, and are ready for sale.

The trade of the catgut and membrane manufacturer is peculiarly disgusting. M. Laboulaye says that the people who work at it always retain the filthy odour communicated by their occupation, even when they are dressed in their holiday clothes, and are enjoying themselves in their own rough way. It is not at all necessary that the disgusting putrefactive odours which accompany this trade should exist. M. Labarraque's *disinfecting liquid* (hypochlorite of soda) has been employed with distinguished success in all the preparatory processes, at a very slight increase of cost, entirely destroying the odour, improving the colour, and in no way injuring the strength of the membrane.

The gut skin used by the gold-beater is prepared from the cæcum of the ox. [See GOLD-BEATING.] For the method of preparing SILKWORM GUT see that head.

CAULKING, see SHIP-BUILDING.

CAUSTIC, any chemical substance which corrodes the skin and flesh: potash is called *common caustic*, and nitrate of silver *lunar caustic*.

CAVIAR, a substance prepared in Russia, consisting of the salted roes of large fish. The best, which is made from the roe of the sturgeon, caught in the Wolga, in the neighbourhood of Astrachan, appears to consist entirely of the eggs: it is packed in small kegs, but the inferior sort is made into the form of dry cakes. It is highly esteemed in Russia, and also forms an article of considerable export; 30,000 barrels having been exported from Astrachan in a single season. The manufacture consists in separating the roe from its membranes, then washing in vinegar or white wine, and drying by spreading it out on a board in the air. Salt is then well rubbed in, and it is next put in a bag and the liquor pressed out. It is then packed in kegs for sale. During the three annual seasons of fasting in Russia, the consumption of caviar is very great, as it is also in Italy during the fasts of the church. It is eaten on bread, with oil and lemon-juice or vinegar.

CEMENTATION, see Steel.

CEMENTS, see Mortars and Cements—Solder.

CENTRE, see Bridge.

CENTRE or CENTER, (Greek κέντρον, a sharp point.) In geometry generally, a point equidistant from the two extremities of a line, or from all similar points of the circumference or boundaries of a surface or solid.

Centre of gravity. That point through which the resultant of the weights of all parts of a body or system of bodies always passes; on which point the body or system would balance in every position. The following are rules for finding the centre of gravity in various figures and solids:—

Triangle. From the middle points of any two sides draw lines to the opposite angles: the intersection of these lines is the point sought. Or, from the middle point of either side draw a line to the opposite angle. The centre of gravity is in this line, at two-thirds of its length from the angle to which the line is drawn.

Parallelogram. The intersection of the two diagonals is the centre of gravity.

Trapezium. Divide it by a diagonal into two triangles; find the centre of gravity of each: then the centre of gravity of the whole is in the line joining these points. Call one of these triangles A B C, and its centre of gravity E. Then, area of whole trapezium : area of triangle A B C :: whole line between the two centres of gravity of triangles : distance of centre of gravity of trapezium from E.

Segment of circle. Divide the cube of half the chord, by three times the area of half the segment. This gives the distance of the centre of gravity from the centre of the circle.

Sector of circle. Multiply the chord by two-thirds of the radius, and divide by the arc. This gives the distance from the centre, as in the last.

Cube or parallelopipedon. At the intersection of any two diagonals.

Cylinder or prism. At the middle of the axis.

Cone or pyramid. In the axis of the solid, at a distance of $\frac{3}{4}$ths the axis from the point.

Generally any figure which is symmetrical about an axis, has its centre of gravity in that axis.

To find this point in a surface unsymmetrical:—Suspend it by a string from any point of its edge, and with a plumb-line mark on the surface the vertical passing through the point of suspension. Repeat this with any other point in its edge, and the intersection of the two lines will be the centre of gravity.

Centre of pressure—in hydrostatics. That point in a surface sustaining the pressure of a fluid, at which the whole pressure may be conceived to act, without altering the equilibrium of the surface, or to which a single force could be applied, to sustain the whole pressure of the fluid and keep the surface in equilibrium. The centre of pressure of a rectangular plane, (whatever be its inclination,) extending to the surface of a fluid, is in the middle of its width, and at a distance of two-thirds its depth from the surface.

The hinges of lock gates, the hoops of vats, and all other contrivances by which the pressure of fluids is to be resisted, should have their places determined in relation to the position of the centre of pressure. For practical application, see Hydrostatics—Inland Navigation, &c.

Centre of oscillation. If a heavy mass be suspended by a thread or string, it can be made to swing to and fro as a pendulum, with a certain definite speed. Now, if all the parts of that mass could vibrate separately, each with the speed due to its distance from the point of suspension, those elements nearest this point would vibrate more quickly than the others which are more remote from it. But as, in fact, the whole mass must vibrate together, the nearer particles are retarded, and the more remote particles are accelerated, by their mutual conjunction into one mass. The whole mass, therefore, vibrates with a speed intermediate between one and the other. That point between the nearer and more remote elements, where the particles just cease to be accelerated and begin to be retarded, is the *centre of oscillation*. If the weight of the whole mass could be *compressed* into this one mathematical point, then this would continue to vibrate with the same speed as the mass before such compression. The length of a common pendulum is measured from the point of suspension to the centre of oscillation, and not to the end of the bob.

Centre of percussion. The centre of percussion is that point in a moving body, or system of bodies, through which the whole effective force of the motion of the body may be conceived to act, and to which point, therefore, if a single obstacle of sufficient strength were opposed, the whole body or system would be stopped, without any tendency to turn round or glance aside from that obstacle. In striking a cricket-ball, we know that there is one point in the bat, on which if the ball impinge no jar or shock will be given to the hand. But if the ball strike above or below this point, the hand is jarred, and even the bat may be broken. This point is the *centre of percussion*.

In a body revolving about a fixed axis or centre, the *centre of oscillation* is in the same point as the *centre of percussion*.

To find the distance of the centre of percussion or oscillation from the point of suspension:—

In a line, small parallelogram, or cylinder, suspended by one end, two-thirds of the axis.

In the cylinder suspended at one end, to two-thirds the square of the altitude add half the radius, and divide this sum by the altitude. If a sphere be suspended from any point outside its surface, square the distance from the point of suspension to the centre of the sphere; to this add two-fifths of the square of the radius, and divide the sum by the distance of the point of suspension from the centre of the sphere.

To find the centre of oscillation or percussion experimentally: suspend the body from the given point, so as to vibrate very freely, and make it oscillate in small arcs. Adjust the length of a thin cylindrical rod so that it may, when suspended freely by one end, oscillate at the same rate as the body to be observed. Two-thirds of the length of this rod will be the distance of the centre of oscillation or percussion of the body from its given point of suspension.

For practical applications we may refer to the pendulum [see HOROLOGY] and to the tilt-hammer [see IRON, Sec. vii.]

Centre of gyration, is a point in a body or system of bodies revolving about a fixed axis, such, that if the whole mass were compressed into that point, any given force would in a given time, cause that point to revolve with the same velocity that it would have given to the body or system of bodies. Hence, in investigations of the velocities which descending weights can be made to communicate to wheels or wheelwork, the calculations are made with respect to the centres of gyration of such wheels.

The distance of the centre of gyration from the axis of rotation is :—

In a circular wheel of uniform thickness, half the radius multiplied by 1.4142.

In a solid sphere revolving about a diameter, the radius multiplied by .6325.

In a circular ring revolving about the centre, the square root of half the sum of the squares of the radii of the outside and inside of the ring.

CERASINE, see GUM.

CERATE, from *cera* wax. A somewhat stiff unguent, made of oil, lard, and wax, with the occasional addition of a substance in powder.

CERINE, see WAX.

CERIUM, a rare metal, named after the planet *Ceres*. The interest which attaches to it is at present purely chemical.

CERUSE, one of the names of white-lead. See LEAD.

CHAIN, see SURVEYING.

CHAIN-CABLES. The greatest improvement that has been made of late years in mooring vessels, has been the introduction of the chain-cable, by Captain Brown of the West India merchant-service, who in 1811 first employed chain-cables in the ship Penelope, of 400 tons burden, of which he was captain. The first chain-cables were of twisted links: Mr. Brunton introduced straight links stayed in the middle with a cross-rod, and in 1828 Mr. Hawkes obtained a patent for constructing these chains with short rods of iron with swells or protuberances about one third of their length from each of their ends, so that when these ends are welded together, the slenderer parts are at the sides, and the thicker at the ends of the elliptic links.

The original cost of a chain-cable is not much more than that of a hempen one, while its durability is infinitely greater as well as the security which it affords, for it is exposed to none of the deteriorating causes which render a hempen cable so little trustworthy. "The alternate wetting and drying which saps the strength of a hempen cable, has no effect on one of iron. The friction against rocks, especially against coral, is often fatal to a hemp cable in a few minutes; but the same friction after weeks of hard use only slightly polishes a few links of the chain. In tropical countries, therefore, the introduction of chain-cables has increased the security of ships at anchor tenfold; but in every climate their advantage is immense. Nor does this advantage consist solely in their strength and durability, for they are managed with much more facility, occupy far less space, and are coiled away with little, or it may be said no trouble at all; for as they are hove in, they fall quietly to and adjust themselves in a box or case near the hatchway, from which they are drawn up when wanted with comparatively small labour. To those who remember the toil and trouble of 'forming a bend' in the cable tier, the wet and the dirt, and the noise made by the numbers of men required to coil it away, these advantages will not be considered as small ones."[1]

On the introduction of the chain cable, the inventor thought it necessary to give his cable a certain degree of elasticity, lest the ship, coming to her bearing on the chain suddenly, might carry it away. With this view, the links of the chain were twisted about half way round, so that when the strain took place, the links by yielding a little, or partly untwisting, might produce an effect somewhat similar to the natural elasticity of hemp. This provision was, however, not necessary, because the weight of the chain was found sufficient to check the impulse, and to act in the same way as elasticity in the hempen cable. Moreover, this twisting of the links tended to weaken them. Accordingly Mr. Brunton took out a patent for an iron cable, in which the iron for the links was not twisted. Each link was oval in form with a broad-headed stay in the middle (as in Fig. 558,) to prevent it from collapsing or shutting up under a heavy strain. Another advantage of this stay is that it prevents the different links from entering each other as they are liable to do in a common chain, thereby entangling the cable. The two shaded circles in this figure are portions of two adjoining links, in section.

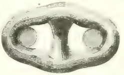
Fig. 558.

The link was further improved by Messrs Acraman of Bristol, who in 1820 took out a patent for the

[1] Encyclopædia Britannica, Art. Navigation.

same. The iron for the links was formed into cylindrical bars of varying diameter, with projections or swells so placed as to come exactly opposite to each other when the bar is turned into a link. (Fig. 559.) The extremities of the bar are scarfed so as to fold over each other a sufficient length, which gives the link in that part when shut or welded additional strength. If the projections are made sufficiently prominent to meet when the bar is turned into a link, they form by their union a very effectual stay, as in Fig. 560 *a*. But if the projections are not sufficiently raised to meet when such bar is turned into a link, the projections are indented or countersunk so as to form two cups of a round, oval, square, or other shape, and a uniting stay is then introduced, and closed in by pressure. The stays are of various lengths and shapes as required. By this contrivance any pressure or strain on the link has the effect of holding the stay tighter and closer in its proper position. A link with a stay of this description is shown in Fig. 560 *b*. A link with the projection not so much raised is shown in Fig. 560 *c*.

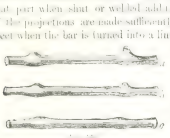

Fig. 559.

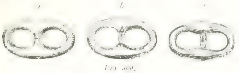

Fig. 560.

The inventor says, that in these forms of link "it is obvious that there are no thin edges or angles in the stay liable to be chipped off, worn away, or injured by pressure or strain, which has in different ways been the case with all the stays hitherto made. Such accidents are completely avoided in the link Fig. 560 *a*, by its containing its strength and resistance purely within itself, and that in so compact a form as to prevent any injury short of an actual removal, forcing or crushing of the particles of the metal out of their places, which must, as is well known, require a very extraordinary power not at all likely to occur in the common use of the article. And in the links, Fig. 560 *b, c*, the same advantages exist in nearly an equal degree, as all pressure or strain from the sides will be made on a smooth stay of iron, opposing in all its parts an equal resistance over a considerable surface."[1]

In 1822, Mr. Sowerby patented a chain cable, a sufficient idea of which will be conveyed by Fig. 561. The opposite sides of each link are bent inwards as at *a*; the sides are held firmly together by a cross bar of malleable iron passing through a block of cast-iron *b*, which cross bar is welded to each side of the link; and for the purpose of preventing the links from entangling, there are small projections on the inner quarters opposite to each other, and next towards the middle of the link as at *c*.[2]

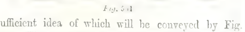

Fig. 561.

In 1828, Mr. Hawks patented an invention for thickening the ends of the links at the points where the greatest friction, and consequently the greatest wear, takes place. The inventor states that chain cables, by reason of the continual friction of the ends of the links against each other, have a great tendency to wear away, so that having been in use a short time, the strength of the links is diminished. The improved links are formed from cylindrical bars produced either by rolling, swageing, or stamping, with projections or swells A A, Fig 562, placed at such distances on the bar as to come exactly opposite each other when the bar is turned into a link, by which means the extremities of the links are made thicker than the sides. The extremities of the bar are scarfed at C D so as to fold over each other, and are welded at the sides of the link. No. 2 shows the bar bent or turned into a link ready to be joined or welded. No. 4 shows the finished link, and No. 3, the same with a stay in the centre.[3]

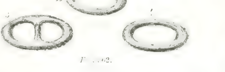

Fig. 562.

As a rope or a cable is no stronger than its weakest part, a single defective link would practically render the whole cable equally defective. The strength of every cable is therefore tried before it is issued, by a machine adapted for the purpose.[4]

As it is sometimes necessary to cut the hempen cable in order suddenly to release the ship, it was necessary to make some provision for severing the chain cable. This is done by means of a bolt and shackle at every fathom or two fathoms, so that by striking out this bolt, the cable is readily detached.

In the use of chain cables, the hawse holes are fitted with strong cases or tubes of iron. Sir Thomas Hardy contrived a stopper by which the cable can be at any time prevented from running out, whatever be the strain upon it. This stopper consists of a large swan-necked bar of tough iron embracing the cable as it comes up the hatchway, having one of the ends of the curve fixed to the beams of the lower deck by means of a powerful bolt, whilst to the other end is attached a tackle, also worked on the lower deck, by

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(1) Repertory of Arts, Manufactures, &c. vol. xl. Second series. London. 1822.

(2) Repertory of Arts, Manufactures, &c. vol. xliii.

(3) Repertory of Patent Inventions, new series, vol. xi. 1831.

(4) A notice of Capt. Brown's proving machine will be found in the article Bridge, p. 226 ante.

which this curved stopper can be drawn tight, and the chain pressed so firmly in its embrace against the angle of the hatchway, that however quickly it may be running out, or whatever strain may be brought on it, the cable is arrested almost immediately.

Another form of cable-stopper, invented by Mr. Batten, is shown in Fig. 563. The apparatus is intended to be fixed under the hatchway of the deck. The whole is of wrought iron: A is an iron plate; B a thick boss of the same, over which the chain or cable I runs; C a lever playing upon a fulcrum D; E an eccentric lever moving upon its fulcrum F, and acting upon the second short lever K. The chain or cable I is nipped or stopped altogether by the extreme ends of each lever being compressed by means of a rope that passes through the pullies G G. In order to set the chain or cable free, the lever may be retracted by a short rope H fastened to the extremity of the lever E.

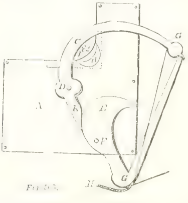

Fig. 563.

When a ship is at anchor the weight of the chain-cable is a great advantage, the strain being exerted on the cable rather than the ship, and this strain must be enormous to draw the cable into a straight line. Instances are related of ships enduring a violent storm of several days, during which 30 or 40 fathoms of their iron cables have been completely polished by contact with rocks and other rough materials. The great weight of these cables is, however, in one respect a disadvantage; for this being added to the weight of the anchor, is so great that they cannot be used in deep water without some modification, which usually consists in combining the hempen with the chain-cable, the anchor being shackled to the latter, and the hempen cable with the top metal link.

The use of chain-cables has been greatly promoted by the fact, that vessels provided with them can be insured on more favourable terms than those which do not possess these improved means of security.

CHAIN-SHOT. Two iron balls linked together by a chain 8 or 10 inches long. They are used in naval warfare, for the purpose chiefly of damaging the enemy's rigging.

CHAIN-WORK, see HOSIERY.

CHALK, one of the numerous forms of carbonate of lime. See LIME.

CHALYBEATE SPRINGS, mineral waters which contain *iron* in such quantity as to form one of their leading ingredients. The term is derived from the Latin *chalybs*, iron or steel. See MINERAL WATERS.

CHARCOAL, see CARBON.

CHART, a plane projection of some part of the sea, for the use of navigation.

CHASING of METALS. The valuable property of malleability possessed by certain metals, admits of their being spread out into sheets: these sheets can be formed into useful and ornamental vessels, &c., by cutting, bending, joining, spinning at the lathe, &c., while the same property of malleability admits of their being raised and embossed by stamping, raising, snarling, chasing, &c. This curious and important subject will be considered under the article RAISED WORKS IN METAL: but the reader who desires to study the subject in detail is referred to the first volume of Mr. Holtzapffel's work on Mechanical Manipulation.

CHEESE. The principal season for cheese-making is from May to September, and it is carried on in nearly every county of England, but there are particular districts which have acquired great repute for the cheese produced therein. The process is in nearly all cases the same. It is well known that milk, after the cream has been removed, will separate, as it becomes sour, into two parts, curd and whey. But this sort of curd would not answer the purpose of the cheese-maker; therefore, the natural process is imitated and hastened by mixing a small quantity of acid with the milk, which has the effect of curdling it without injuring its quality. The acid commonly used is rennet, a preparation of the gastric juice from the stomach of a sucking calf. Experience teaches the quantity of rennet necessary to curdle a certain quantity of milk, the milk being previously coloured with annotto, to the tint required for the description of cheese about to be made. When the curd has formed and is firm enough to be separated from the whey, the dairy-woman plunges her hands to the bottom of the cheese-tub, and with a small wooden disk stirs and breaks the curd, which process she afterwards completes with her hands, carefully breaking up every lump, and reducing the whole to fragments no larger than a hazel nut. This may also be done by the *curd-cutter*, Fig. 564, an oval hoop of copper, with a stem of round copper rod and a wooden handle. When the curd is thoroughly divided it sinks to the bottom of the tub, and the whey is then ladled off from it, and sent to the hog-tub, or set aside for whey-butter. Care is taken to press out all the whey from the curd by means of the lading dish and the hands, after which

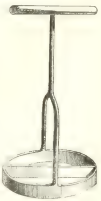

Fig. 564.

the curd is cut through in squares with a knife to allow any remaining whey to flow from it. The curd is now ready for the vat or mould in which it is to be shaped into a cheese. This is made of elm wood, as being least liable to burst with pressure; it is pierced with holes at the bottom, to allow the whey to escape, and has also a strong wooden cover. In filling the vat a cheese cloth is spread loosely over it, and the curd after further breaking up and squeezing, is pressed into the vat and piled up on the top in a rounded form. The ends of the cheese-cloth are then folded over, and the vat with its contents, placed in the cheese-press, where it receives a degree of pressure varying with the size of the cheese. Cheese presses are of several kinds, the simplest being merely a long beam, one end of which is frequently placed in a hole in the wall, while the other is loaded with weights, the cheese vat being placed between the two. Another form is a timber frame, within which is a large square stone capable of being raised and lowered over the vat at pleasure. A third is a cast-iron press, Fig. 565, or frame, with a perpendicular piston arranged to cover the sinker of the cheese-vat, and raised or lowered by a small pinion attached to a ratchet wheel and lever three feet long. The lever is grooved on the upper side to hold the ring of the weight for increasing or diminishing the power in proportion to the distance from the ratchet wheel. The pressure of this instrument can be made to equal about 20 tons, and its cost is about four-and-twenty shillings. The vat containing the cheese remains under pressure at first for about three hours; it is then taken out, the cheese removed and allowed to stand for an hour or two in a vessel of hot whey, for the purpose of hardening the outer coat: it is then wiped dry, left to cool, and then covered with a clean cloth and returned to the vat, which has also been wiped dry. Another three hours' pressure, and it is again taken out, but merely for the purpose of wrapping it in a dry cloth and returning it to the vat. This is continued twice a-day for two days, the cheese being turned each time in the vat: it is then finally removed from the press and carried in the vat to the salting tub. In all the above processes, the state of the cheese-cloths is of great importance: they are of coarse linen of an open texture, and are repeatedly washed and wrung out in boiling-water without soap. An abundance of clean dry cloths for wiping out dairy vessels after they are washed, is an indispensable item in the furniture of a dairy.

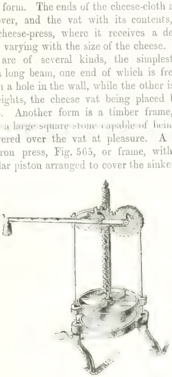
Fig. 565

The cheese in its vat is next covered with brine in the salting-tub, and remains several days, being regularly turned each day. It is then removed from the vat to a salting-bench, where it stands for a week or ten days, being carefully rubbed with salt every day. If the cheese is large, a wooden hoop or a fillet of cloth is put round it to prevent it from cracking. When sufficiently salted it is removed to the drying-bench and thence to the cheese-room, where its future management consists chiefly of wipings and turnings, and regulations as to ventilation. In Cheshire cheese the salt is well mixed with the curd, and not merely rubbed on the outside.

This, which is the most celebrated English cheese, is made in quantities amounting to nearly 14,000 tons annually. The rich cheese called Stilton is made in Leicestershire: it is not sufficiently mellow for use, under two years old. Double and single Gloucester cheese is also well known. The former is made of the milk and cream, the latter of the milk and half the cream. Bath and York are famous for cream cheeses.

Good cheeses are produced in large quantities in Holland. In Gouda cheese, which is considered the best made in that country, muriatic acid is used instead of rennet. Hence it is never infested with mites. Parmesan cheese, from Parma, in Italy, is skim-milk cheese, owing its rich flavour simply to the fine herbage on the banks of the river Po. Swiss cheese, especially that of Gruyère, is pleasing to some tastes. It is flavoured with herbs. Our chief imports of cheese have hitherto been from Holland, but within the last few years a large quantity has been received from the United States. In 1847, this latter amounted to 109,322 cwts. The duties previous to 1842, were 10*s*. 6*d*. per cwt. on all descriptions of foreign cheese; but in that year, cheese from a British possession was admitted at 2*s*. 6*d*. per cwt. duty. In 1846 a further reduction took place, the foreign being admitted at 5*s*. per cwt., and that from British possessions at 1*s*. 6*d*. The article is now free. In 1858 the quantities imported amounted to 364,087 cwts.; in 1859 to 406,547 cwts.; and in 1860, to 583,283 cwts.

CHICORY, a root of the endive or dandelion family, used for mixing with coffee. It is cultivated largely in Germany, and is exported to this country from Hamburg in large quantities. It is also grown in Yorkshire, Lincolnshire, and Suffolk. The seed is sown in April, and the harvest is gathered in September. The roots are pulled up and washed: they are then cut across into pieces about the size of a walnut and dried at a kiln, by which means 4 or 5 tons are reduced to 1 ton. It thus arrives in London in a dried shrivelled up state, in pieces resembling the cross sections of a parsnip. It is of a whitish colour, almost tasteless, and very light with respect to its bulk. To prepare it for use it is roasted in the same manner as coffee, [see COFFEE,] which changes it into a blackish brown colour. It is then spread out in shallow boxes or coolers, and when cold it is picked by hand for the purpose of separating portions of wood or stone that may by accident have got in. The roasted and sorted chicory is next ground by the action of two massive granite-edge runners, Fig. 566, to which motion is given by a vertical axis, to which they are connected by means of two short horizontal axes projecting from the vertical one. The granite runners thus moving upon their horizontal axis by their contact with the bed, pass constantly round by the motion of the vertical axis and crush the material which is thrown in. The bed-stone is also of granite 2 feet thick, and weighing 2½ tons. This is surrounded by a sheet-iron border, and as the chicory is crushed out by the action of the runners, it is collected and thrown under them again by means of a scraper, adjusted to the proper curve and mounted on an axis parallel with the central axis: this scraper can also be adjusted to different heights. When the chicory is sufficiently crushed, a hopper is opened at the side, and the powder is discharged into a vessel placed to receive it. It is then bolted through sieves to different degrees of fineness, after which it is ready for sale. According to another method, the roasted chicory is crushed into nibs, which are again picked over and then sorted into sizes by bolting. These nibs, as well as the powder, are sold by the grocers.

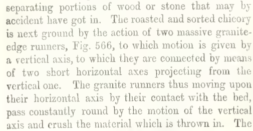
Fig. 566. GRINDING CHICORY.

The powdered chicory resembles coffee, but is finer in the grain and of a lighter brown colour. When put into water it melts almost entirely away. It soils the fingers more than coffee, and on this account may be distinguished therefrom. The presence of chicory may be detected in coffee by putting a spoonful of coffee gently into a tumbler of clear cold water: if pure it will float on the surface; if not, the chicory will separate and discolour the water as it subsides. In Germany the infusion of chicory is taken as a beverage by persons in humble life: in this state the flavour is that of a sharp sweetish wort, resembling the taste of liquorice, and in colour similar to that of dark sherry.

In its fresh state chicory, or succory *(Cichorium Intybus)*, is said to be a good tonic, and to have the effect of an aperient. The dandelion tribe is so widely diffused that it is probably intended by nature for the benefit of man and animals. The presence of chicory in coffee is said to give *body* to that beverage, to deepen its colour, and to assist that soft and pleasing aroma which makes coffee acceptable. This however is very doubtful. It may also diminish, in some degree, the constrictive effects of coffee. The proper proportion is 2oz. of chicory to 16oz. of coffee, and if a larger proportion be added and the price of coffee be charged, the addition of the cheaper article is a fraud. It is stated that half, or even two-thirds chicory is sometimes added. Of course the only safeguard for the consumer is to grind his own coffee and add the chicory himself. It is stated that in 1848, for 36,000,000lbs. of coffee, 12,000,000lbs. of chicory were sold; and some time ago it was proposed in parliament to impose a duty of 4*d.* per lb. on home dried chicory, with a view of lessening the use of it, or even of throwing it out of use altogether, as was effectually done some years ago, in the case of Hunt's celebrated roasted corn. It was stated, however, that the moderate use of chicory helps the sale of coffee. In April 1844, when a debate on the budget took place in the House of Commons, Mr. Baring observed that "we were mistaken about chicory, in thinking that the use of it prevented the consumption of coffee: he believed that chicory was mixed to a large extent with bad coffee. When Lord Spencer first proposed the reduction of the duty on chicory, the result was, that a certain amount of bad coffee, which would not pass in the market, was by admixture with chicory made to go down. People were wrong in supposing that chicory made bad coffee; he believed that the foreign coffee, which we so much preferred, contained one-third chicory. Cross the channel, and in point of fact all the coffee you drink contains one-third part of chicory."

A correspondent in *Chambers's Edinburgh Journal* (No. 304, N. S.) states that chicory must be regarded altogether as an adulterant: that the best coffee all over the continent is obtained by *roasting high*. "The rule is to roast as high as possible without burning; and the higher the roasting which the bean will stand, the better will be the coffee. When the beans are too ripe, the fine pale green colour has vanished and they are sooner burnt; and likewise, when unequal in size, one portion will burn before the other is highly enough roasted. To make the beverage good, a large quantity of ground coffee must be used, and the pot must never by any means be allowed to boil. Abundance of sugar is likewise necessary."

Prussian chicory is considered as the best. British chicory when roasted is much paler in colour and of inferior value. A factitious colour is given to it by means of Venetian red (sesquioxide of iron). The great demand for chicory has led to its extensive adulteration; first, by what is called *Hambro' powder*, which consists of roasted and ground peas, damaged corn, &c., coloured with Venetian red; and secondly, by *coffee flights*, the thin membrane which separates from coffee seeds in the act of roasting. Parsnips, turnips, &c. are also sliced and roasted as substitutes for chicory. Chicory is used for adulterating snuff, and for colouring porter. [See APPENDIX.]

CHIMNEY, (French *cheminée*, from Latin *caminus*, a furnace,) a contrivance for carrying off the smoke of a fire or furnace. It also increases the draught of the fire, and promotes the ventilation of the house or room from which it opens. History has failed to record the inventor, or to define the place where the chimney was first used. Chimneys seem to have been common at Venice before the middle of the fourteenth century. An inscription over the gate of the school of Santa Maria della Carita states, that in 1347, a great many chimneys were thrown down by an earthquake, a fact which is confirmed by John Villani, who refers the event to the evening of the 25th of January. Chimneys had also been in use at Padua before 1368, for in that year Galeazo Gataro relates, that Francisco da Carraro, lord of Padua, came to Rome, and finding no chimneys in the inn where he lodged, because at that time fire was kindled in a hole in the middle of the floor, he caused two chimneys, like those that had been long used in Padua, to be constructed by the workpeople he had brought with him. Over these chimneys, the first ever seen in Rome, he affixed his arms, which were remaining in the time of Gataro. Winwall House, in Norfolk, which has been described as the most ancient and perfect specimen of Norman domestic architecture in the kingdom, has not only recessed hearths, but flues rising from them, carried up in the external and internal walls. Now, if Winwall House really be an Anglo-Norman edifice, its chimneys must have been built in the twelfth century, and, consequently, the claim of the Italians to the invention cannot be supported. The chimneys at Kenilworth and Conway were also probably erected anterior to the date of those on which the Italians rest their claim. Leland, also, in his account of Bolton Castle, which he says was "finished or Kynge Richard the 2 dyed," notices the chimneys. "One thynge I muche notyd in the hawle of Bolton, how chimeneys were conveyed by tunnells made on the syds of the walls betwyxt the lights in the hawle, and by the means, and by no covers, is the smoke of the harthe in the hawle wonder strangely conveyed."

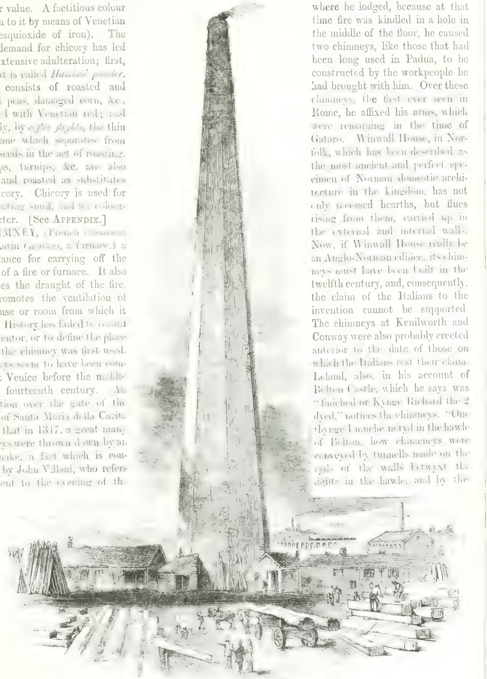

Fig. 567. OCTAGONAL CHIMNEY SHAFT AT BOLTON.
Erected in 1842. Height, [illegible] feet. Cost, about £3,000. Material, [illegible]

During the reigns of the Tudors, the chimney shaft became a prominent and beautiful feature in buildings. When once introduced into England, the merits of chimneys were soon appreciated, for we find it stated, that in the reign of Queen Elizabeth, apologies were made to visitors if they could not be accommodated with rooms provided with chimneys, and ladies were frequently sent out to other houses, where they could have the enjoyment of this luxury, for such it must be called at this period, when the poorer class of houses was not yet furnished with it.

The first object proposed to be accomplished by chimneys was to discharge into the air the products of combustion, instead of allowing them to spread over the apartment. With the huge wood fires of our ancestors, the large hearth recess and the capacious flue did not interfere with the accomplishment of the object proposed; but when fire-places were introduced into small rooms, and coal was substituted for wood, the arrangements which were suited to the baronial hall or kitchen did not apply. Science was unable, or did not condescend, to investigate the subject, and thus the defects of chimneys continued to exist through many generations. One great defect arose from the great capacity of the flue in proportion to the extent of the fire, the heat of which was often insufficient to determine an upward current for carrying off the smoke. It is now a matter of every day experience, that the force of the draught in a chimney is so much the greater as the column of air which passes up it is longer or more heated; or, in other words, the taller the chimney, or the hotter the fire, the more rapid will be the draught. The ascentional force of this current is the difference between the weight of the column of heated air in the chimney, and a column of the surrounding atmosphere of equal height. The draught therefore is increased by increasing the perpendicular height of the chimney. Its length in a horizontal direction does not increase, but diminishes the draught, by cooling the air before it gets into the effective part of the flue. The draught is also increased, by making all the air which enters the chimney pass through or very near the fuel; for when much air gets into the chimney above the fire, by having a high mantel-piece, the mass of air in the chimney cannot get sufficiently heated.

It is a law of expansion for atmospheric air and all gases, that they dilate almost equally and very nearly in proportion to the increase of temperature. According to Gay Lussac, 1,000 cubic inches of air at the freezing temperature increase in bulk to 1,375 cubic inches at the temperature of boiling water. For an increase of temperature, therefore, from 32° to 212°, amounting to 180°, the increase of volume is 375 parts in 1,000, or $\frac{3}{8}$ of the whole bulk; and since the expansion is uniform, the increase of volume for 1° will be found by dividing this by 180, which will give an increase of $20\frac{5}{6}$ parts in 10,000 for 1° of Fahrenheit's thermometer. The recent experiments by Magnus and Regnault have thrown a doubt on the correctness of this result. By methods perfectly independent of each other, these philosophers have arrived at 0.3665, instead of 0.375, as the true co-efficient for the expansion of atmospheric air.

Now as this law of expansion applies equally to air in motion as to air in a state of rest, we can thus calculate the amount of dilatation undergone by the column of air in a chimney from the heat of the fire in the grate. But as the heat is constantly varying, so also is the volume of ascending air. The air of the room which passes through the fire and undergoes a chemical change is intensely heated, and passing up the flue becomes reduced in temperature at every step. The air which rushes into the cavity above the fire becomes also suddenly expanded, rises, and, mingling with the heated gaseous products of combustion, diminishes somewhat of their temperature while it augments their bulk. The mean temperature of the heated ascending column may be found by taking the temperature a short distance above the burning fuel, and also at the top of the chimney; by adding these two results together, and dividing by two, we get the mean temperature, or a near approximation thereto. We are then able to calculate the force of the draught by applying one of those rules which scientific men have formed for the purpose. The method of calculation proposed by Montgolfier is very simple, and appears, from recent inquiries, to be accurate. It is this:—Ascertain the difference in height between two equal columns of air when one is heated to a certain temperature, the other being the temperature of the external air, and the force of the draught, or the rate of efflux, is equal to the velocity that a heavy body would acquire by falling freely through this difference of height.

Now the space through which a heavy body falls in perpendicular height in one second is rather more than sixteen feet; but, by the law of accelerating forces, the velocity of a falling body at the end of any given time is such as would carry it, in an equal time, through twice the space through which it has fallen in that time; or the velocity in feet per second is equal to 8 times the square root of the number of feet in the fall; or, to the square root of the number obtained by multiplying 64 by the height of the fall in feet.

When the force of the draught of a chimney is the difference in weight between two columns of air caused by the expansion of one of these columns by heat, the decimal 00208 which represents the expansion of air by 1° of Fahrenheit must be multiplied by the number of degrees the temperature is raised, and this product again by the height of the heated column. Thus if the height of the column is 50 feet, and the increase of temperature 20°, we have $20 \times .00208 \times 50 = 2.08$ feet; or 52.08 feet of hot air will balance 50 feet of the cold air; and the velocity of efflux of the heated column when pressed by the greater weight of the colder column will be equal to $8\sqrt{2.08} = 11.54$ feet per second.

The mean temperature of the heated ascending current in a chimney is much greater than 20° above that of the colder column with which it is compared; but it is most probable that air expands more proportionally at high temperatures than at low ones for equal increments of heat. As the law of expansion for high temperatures has not, as far as we know, been determined, it was thought better to select an example within the range of our knowledge, than to assume a higher temperature, which would more nearly represent the conditions of the case.

By the same means, the efflux of air, under any given pressure, can also be calculated. The pressure being known, we calculate the height of a column of air equal in weight to this pressure. Thus if the pressure be equal to one inch of mercury, water is 827 times the weight of air, and mercury 13.5 times the weight of water; therefore $827 \times 13.5 = 11\,164$ inches, or 930.4 feet; and according to the rule $8\sqrt{930.4} = 244$ feet per second for the velocity of efflux under the pressure of one inch of mercury.

In these cases, however, there must be an allowance for loss by friction, which will vary according to the nature and size of the chimney shaft, and also according to the velocity of the air. The retardation of the air by friction, in passing through straight tubes, will be directly as the length of the tube and the square of the velocity, and inversely as the diameter.

In this way the action of chimneys is brought within the domain of science. There are, however, practical difficulties and special cases which usually come under the treatment of the smoke-doctor; these may all be resolved by reference to well-known scientific principles, but, unfortunately, the smoke-doctor is not always—indeed, very seldom, a man of science. The following cases of smoky chimneys and the method of cure will include as much as need be said on this subject.

Chimneys may smoke for want of a sufficient supply of air. This is sometimes the case in a new house, where doors and windows fit tightly and accurately, so that scarcely a chink is left for the admission of air. Or, if the house be not new, the windows and doors are often listed, sandbags are placed over the junction of the two window-frames, and a thick mat closes the bottom of the door, and even the key-hole is often stopped. It is no wonder that, under such circumstances, the chimney should smoke; for the air necessary to support the fire must come down the chimney (the only way left for it) instead of passing through the fire and up it. To ascertain in a rough way how much air is required per minute to make the fire burn well without smoking, set the door open until the fire is burning properly, then gradually close it until smoke again begins to appear. Then open it a little wider, and hold it in such a position as will admit the necessary supply. Now observe the width of the open crevice between the edge of the door and the rabbet into which it would shut. Suppose this distance to be half an inch in a door eight feet high; the room would, in such a case, require for the entrance of the air an aperture equal to 48 square inches, or a hole six inches by eight inches. This, however, would be more than is usually required. Dr. Franklin found that a square opening of six inches to the side was a good medium size for most chimneys. But now comes the difficulty, (at least in English houses, where no air duct is provided by the architect and builder, as in the Polignac fire-place,) where to make this opening. If made in the door, it not only interferes with the privacy of the room, but admits of cold draught to the back and feet of those sitting near the fire; if made in the window, it brings a cataract of cold air down upon the heads of the inmates.

It has been proposed to cut a crevice in the upper part of the window-frame, and to place below this a thin shelf, sloping upwards, in order to direct the air towards the ceiling, where, mingling with the heated air of the apartment, it would mitigate its temperature, and bring it down again to feed the fire. The objection to this plan is, that it would cool the room; but as fresh air admitted from any other source would have a similar cooling effect, it is not easy to propose a better plan. An old-fashioned contrivance for kitchens was to place in one of the spaces of the window-frame a circular tin plate, containing a wheel mounted on an axis, the radii or vanes being bent obliquely: these being acted on by the entering air, forced it round like the vanes of a windmill, and at the same time dispersed the air to a certain extent, and prevented a distinct draught from being felt. Another method was to take out a pane of glass and substitute a tin frame, giving it two springing angular sides, and being furnished with hinges below, it could be drawn in more or less above, so that the incoming air might be directed upwards, and regulated as to quantity A contrivance has lately been introduced for ventilating rooms; but when there is a fire in the room, it must serve the purpose of introducing air instead of letting it out. It consists of a number of strips of plate glass, arranged after the fashion of a Venetian blind, occupying the position of one of the panes of glass in the upper window-frame. By a little adjusting motion, the strips can be separated more or less apart to regulate the supply of air, or closed entirely, so as to exclude it. Perforated panes of glass have also been introduced as ventilators; but they must also bring air into the room instead of letting it out, when a fire is burning.

A second cause of smoky chimneys arises from the size of the fire-place; it may be too wide or too high. Dr. Franklin recommended that the openings in the lower rooms should be about 30 inches square and 18 deep; and those in the upper rooms only 18 inches square and not quite so deep; the intermediate openings diminishing in proportion to the height of the funnel.

But the funnel itself may be too high compared with the size of the fire. The hot air ascending to a certain height may distribute its heat to the air in the upper part of the flue, so that the whole may cool down, and the column within the flue be nearly of the same weight as an equal column on the outside. In such a case, there will be little or no draught to carry off the smoke, and it will, therefore, enter the room.

But it more frequently happens that the funnel is too short. The remedy in such case is to contract the opening of the chimney, so as to force all the air that enters to pass through or very near the fire.

In some houses, instead of having a separate chimney for each room or fire-place, the flue is bent or turned from an upper room into the flue of another fire from below. In such a case, the upper chimney is too short, since the length can only be estimated from the place where it enters the flue of the lower room; and this, in its turn, is also shortened in efficient length by the distance between the entrance at the second funnel and the top of the stack; for all that part being supplied with air from the second funnel, adds no force to the draught; and if there is no fire in the second chimney, it cools the hot current of the first, and so diminishes the draught. The remedy in this case is to close the opening of that chimney in which there is no fire.

Chimneys often overpower each other, and so cause them to smoke. If, for example, there are two fire-places in one large room, with fires in each, and the doors and windows closed; if the two fires do not burn equally well, either from not being lighted at the same time, or not equally supplied with fuel, or from any other cause, the stronger fire will overpower the weaker, and draw the air down its funnel to supply its own demand. The air descending the funnel of the weaker fire brings the smoke with it, and thus fills the room. Two chimneys in different rooms which communicate by a door may also act in this way whenever the door is opened; so, also, in a house where all the doors and windows fit tightly, a strong kitchen chimney on the lowest floor may overpower any other chimney in the house, and draw air and smoke into the rooms as often as a door communicating with the staircase is opened. Dr. Franklin mentions the case of a nobleman's house in Westminster afflicted with this troublesome complaint. It was a new house, and after the owner had paid for it, and discharged all claims, he had to expend 300*l.* more before the smoky chimneys were cured. Of course, the only remedy for this disorder is, to provide each room with the means of furnishing the fire-place with a sufficient supply of air for the combustion of the fuel. When will architects and builders be convinced of the fact, that fire-places, as well as human beings, require constant supplies of fresh air, and that it is their duty to provide every room with air-channels, placed so as to feed the fire without annoying the inmates?

Another fruitful source of smoky chimneys is, when their tops are commanded by higher buildings, or by a hill, so that the wind blowing over them, falls like water over a dam, sometimes almost passing over the tops of the chimneys, and beating down the smoke. If the funnels cannot be raised, so that their tops may be of the same height, or higher than the eminence, the only remedy is to mount one of those ugly contrivances with which the chimney doctors delight to satirise the architect and builder, and which are thus enumerated by an amusing writer in Chambers's *Edinburgh Journal*:—"The simplest of all consists in the well-known revolving bonnets or cowls, with wind-arrows on their summits; which, by the way, were once called Bishops in Scotland, while a friend assures me, that in the west of England he has heard them styled Presbyterians. The philosophy of this contrivance is sufficiently simple, in whichever direction the wind blows, the mouth of the chimney is averted from it. This principle has its development in a thousand devices—some looking like Dutch ovens come up to see the world, some like half sections of sugar loaves, some like capital H's, and sundry other pleasing objects. The red chimney-pots, too, have contrivances of a similar intention, in the diverging spouts and cavities and twists which some of them delight in. A different species, is the perforated whirling variety, which seem pertually whizzing round for the mere fun of the thing, since any good they do is extremely apt to escape detection. They are a lively-looking apparatus; but on squally nights, and when the pivot becomes a little rusty, the musical sounds they give forth can scarcely be considered agreeable. Among the more ingenious of smoke-curers, an invention of recent origin, named the *Archimedean screw ventilator*, deserves a place. It consists, as its name implies, of wind-vanes attached to the extremity of a revolving screw. When the wind strikes these vanes, it produces a rapid revolution of the screw, which is thus supposed to *wind up* the smoke or vitiated air from below. Perhaps it serves the proposed end; but whether the positive advantage thus gained is not lost by the obstruction of such apparatus to the free passage of smoke in calm weather, is a point, in my estimation, more than questionable. For the relief of such chimneys as only smoke in windy weather, perhaps, this and other forms of external apparatus are best adapted. Another invention of equal merit, is a chimney-cap of metal externally grooved in a series of spiral curves up the pipe, which end in a kind of mouth-piece, from whence the smoke issues. The wind, when impelled against this apparatus, is supposed to take somewhat of the direction of the spiral grooves, and thus to form an upward current to assist the emission of the smoke." One of the most recent of this class of inventions is *Day's wind-guard*, which consists of an octagonal metallic chimney-cap, having four slits in it, which are protected by projecting pieces or slips of metal. When a current of air strikes in any direction against the cap, it reflects or turns the air in such a manner, as immediately to produce a draught up the pipe. "In casting one's eye down the long streets of the smoky city, in taking a survey of the roofs and their tormented chimneys, the infinity of other contrivances is so great, that it is scarcely a poetical hyperbole to say our pen starts back from it. Here is patent upon patent, scheme after scheme, each doing its best, no doubt, to obtain the mastery over that simple thing—smoke; and each with a degree of success of a very hopeless amount. There appears to me something intensely ludicrous in these struggles against what seems to be an absurd, but an invincible foe; the very element of whose success against us lies in our not strangling him in his birth. Many obstacles are in the way, no doubt; there are obstacles in the way of every good; but I have little doubt, that had the perverted ingenuity which has mis-spent itself upon the chimney-pots been directed to the fire-place, we might have now had a different tale to tell. The smoke nuisance is laughed at as a minor evil, by a great practical people like ourselves, who heroically make up their minds to put up with it;

but when it is considered as an item in the comfort, cleanliness, and health of a whole nation, it assumes, or should assume a different position."

We do not by any means affirm that the above contrivances are always effectual in the cure of smoky chimneys; for it is easy to imagine cases where chimneys will, or rather must smoke, in spite of the whole host of caps, cowls, and vanes. For example, when a commanding eminence is further from the wind than the chimney commanded, the wind would, as it were, be dammed up between the house and the eminence, and force its way down the chimneys in whatever position the turn-cap or other contrivance might be situated. Dr. Franklin mentions a city in which many houses were tormented with smoky chimneys by this operation, for their kitchens being built behind, and connected by a passage with the houses, the tops of the kitchen chimneys were thus lower than the tops of the houses, and thus, when the wind blew against the backs of the houses, the whole side of a street formed a dam, and the obstructed wind was forced down the kitchen chimneys, and passed along the passages into the houses, and so into the street. This was especially the case when the kitchen fires were burning badly. In summer the annoyance assumed a different form, for the smoke was wafted from the kitchen chimneys into the chambers of the upper rooms.

Chimneys, which otherwise draw well, will often smoke from the improper situation of a door. Thus when the door and the chimney are on the same side of the room, and the door, being in the corner, is made to open against the wall, as is usually done, to have it more out of the way, it follows that, when the door is partly opened, a current of air rushes in and passes along the wall into and across the opening of the fire-place, and whisks the smoke into the room. This happens more frequently when the door is being shut, for then the force of the current is increased, and persons sitting near the fire feel all the inconvenience both of the draught and the smoke. A remedy may be found by an intervening screen, projecting from the wall and passing round a great part of the fire-place; or still better, by shifting the hinges of the door, so as to throw the air along the other wall.

A room with no fire in it is sometimes filled with smoke from the funnel of another room, in which a fire is burning. This arises from changes in density of the air in the cold funnel, from changes in temperature by day and by night, as well as from changes in the direction of the wind. It is found that when the temperature of the outer air and of that in the funnels is nearly equal, the air begins to ascend the funnels as the cool of the evening comes on, and this current will continue till nine or ten o'clock next morning; then, as the heat of day approaches, it sets downwards and continues to do so till evening; it then changes again and continues to go upwards during the night. Now when the smoke from the tops of neighbouring funnels passes over the tops of funnels which are drawing downwards, the smoke is also drawn down and descends with the air into the chamber. The remedy proposed by Dr. Franklin, was to contract the opening of the chimney to about two feet between the jambs, and to bring the breast down to about three feet of the hearth. An iron frame is then placed just under the breast, and extended to the back of the chimney, so that a plate of iron may slide horizontally backwards and forwards in the grooves on each side of the frame; this plate, when thrust quite in, fills up the whole space, and shuts up the chimney entirely when there is no fire. But when there is a fire, it can be drawn out, so as to leave between its further edge and the back, a space of about two inches, which is sufficient for the smoke to pass; and so large a part of the funnel being stopped by the rest of the plate, the passage of warm air out of the room up the chimney is in great measure prevented, as is also the cold air from crevices to supply its place. The effect is seen in three ways:—1. When the fire burns briskly in cold weather, the howling or whisking of the wind, as it enters the room through the crevices when the chimney is open, ceases as soon as the plate is slid in to its proper distance. 2. Opening the door of the room about half an inch, and holding the hand against the opening near the top of the door, you feel the cold air coming in against your hand, but weakly if the plate be in. Let another person draw it out, so as to let the air of the room go up the chimney with its usual freedom in open chimneys, and you immediately feel the cold air rushing in strongly. 3. If something be set against the door, just sufficient when the plate is in to keep the door nearly shut, by resisting the pressure of the air that would force it open, then, when the plate is drawn out, the door will be forced open by the increased pressure of the outward cold air endeavouring to get in, to supply the place of the warm air that now passes out of the room to go up the chimney. "In our common open chimneys," says the Doctor, "half of the fuel is wasted, and its effect lost; the air it has warmed being immediately drawn off."

The form of the chimney-pot has also an influence on the free passage of the smoke. Many of those fancy chimney-pots ornamented, singly or clustered together, will cause the chimneys to smoke in strong winds; the ornaments serving as points of resistance to the wind, after reflecting it down the chimney; and the clustered arrangement presenting a broad resisting surface, so that the wind, in blowing against them, rises up along the surface, and blows strongly over the mouths of the pots, so that the smoke cannot force its way through the blast. In Venice, the top of the flue is rounded into the true form of a funnel, and this is often found to answer the purpose; but, at present, we do not know of any remedy except a turn-cap, or one of the many elegant contrivances which give such wonderful variety to the sky line of most of our houses and public buildings.

Cases of smoky chimneys may arise, which may puzzle the science of the most accomplished smoke doctor. We borrow two such cases from Franklin. "I once lodged," he says, "in a house in London, which, in a little room, had a single chimney and funnel. The opening was very small, yet it did not keep in the smoke, and all attempts to have a fire in this room were fruitless. I could not imagine the reason; till at length, observing that the chamber over it, which had no fire-place in it, was always filled with smoke when a fire was kindled below, and that the smoke came through the cracks and crevices of the wainscot, I had the wainscot taken down, and discovered that the funnel which went up behind it, had a crack many feet in length, and wide enough to admit my arm; a breach very dangerous with regard to fire, and occasioned, probably, by an apparent irregular settling of one side of the house. The air entering this breach freely, destroyed the drawing force of the funnel. The remedy would have been, filling up the breach, or rather rebuilding the funnel; but the landlord rather chose to stop up the chimney."

The second case occurred at the house of a friend near London. "His best room had a chimney, in which he told me he never could have a fire, for all the smoke came out into the room. I flattered myself I could easily find the cause, and prescribe the cure. I opened the door, and perceived it was not want of air. I made a temporary contraction of the opening of the chimney, and found that it was not its being too large that caused the smoke to issue. I went and looked up at the top of the chimney, its funnel was joined in the same stack with others, some of them shorter, that drew very well, and I saw nothing to prevent its doing the same. In fine, after every other examination I could think of, I was obliged to own the insufficiency of my skill. But my friend, who made no pretension to such kind of knowledge, afterwards discovered the cause himself. He got to the top of the funnel by a ladder, and looking down, found it filled with twigs and straw cemented by earth, and lined with feathers. It seems, the house, after being built, had stood empty some years before he occupied it; and he concluded that some large birds had taken the advantage of its retired situation to make their nests there. The rubbish, considerable in quantity, being removed, and the funnel cleared, the chimney drew well, and gave satisfaction."

It has been remarked, that chimneys situated in the north wall of a house, do not draw so well as those in a south wall; because when cooled by north winds, they are apt to draw downwards. Hence, chimneys enclosed in the body of a house are more favourably situated than those in exposed walls. Chimneys in stacks often draw better than separate funnels, because those that have constant fires in them warm those in which there are none.

Ascending and descending currents in chimneys are thus explained by Dr. Franklin:—"In the summer time, when no fire is made in the chimneys, there is, nevertheless, a regular draft of air through them, continually passing upwards from about five or six o'clock in the afternoon, till eight or nine o'clock next morning, when the current begins to slacken and hesitate a little for about half an hour, and then sets as strongly down again, which it continues to do till towards five in the afternoon, then slackens and hesitates as before, going sometimes a little up, then a little down, till, in about half an hour, it gets into a steady upward current for the night, which continues till eight or nine the next day; the hours varying a little as the days lengthen and shorten, and sometimes varying from sudden changes in the weather; as, if, after being long warm, it should begin to grow cold about noon, while the air was coming down the chimney, the current will then change earlier than the usual hour, &c. This property in chimneys, I imagine, we might turn to some account, and render improper for the future the old saying, 'As useless as a chimney in summer.'" The doctor then shows how the chimney might be converted into a cool larder for summer, and then goes on to explain the cause of the phænomena he has described. "In summer time there is generally a great difference in the warmth of the air at mid-day and midnight, and, of course, a difference of specific gravity in the air, as, the more it is warmed, the more it is rarefied. The funnel of a chimney, being for the most part surrounded by the house, is protected, in a great measure, from the direct action of the sun's rays, and also from the coldness of the night air. It thence preserves a middle temperature between the heat of the day and the coldness of the night. This middle temperature it communicates to the air contained in it. If the state of the outward air be cooler than that in the funnel of the chimney, it will, by being heavier, force it to rise, and go out at the top. What supplies its place from below, being warmed in its turn by the warmer funnel, is likewise forced up by the colder and weightier air below; and so the current is continued till the next day, when the sun gradually changes the state of the outward air, makes it first as warm as the funnel of the chimney can make it, (when the current begins to hesitate,) and afterwards, warmer. Then, the funnel, being cooler than the air that comes into it, cools that air, makes it heavier than the outward air,—of course, it descends; and what succeeds it from above, being cooled in its turn, the descending current continues till towards the evening, when it again hesitates, and changes its course, from the change of warmth in the outward air, and the nearly remaining same middle temperature in the funnel. . . . If that part of the funnel of a chimney which appears above the roof of a house be pretty long, and have three of its sides exposed to the heat of the sun successively—viz. when he is in the east, in the south, and in the west, while the north side is sheltered by the building from the cool northerly winds, such a chimney will be often so heated by the sun, as to continue the draft strongly upwards through the whole twenty-four hours, and often for many days together. If the outside of such a chimney be painted black, the effect will be still greater, and the current stronger."

Wide chimneys are not so liable to have their draught affected by strong winds as narrow ones. It is therefore desirable to build them tolerably wide, and to reduce the width, if necessary, by means of a sliding register-plate. When a number of furnace flues are conducted into one vertical chimney-stalk, the draught of the several fires is improved, and the products of combustion are conveniently got rid of.

A great improvement has taken place of late years in the building of these costly structures. The usual expensive scaffolding is entirely superseded, by leaving recesses within the chimney at regular intervals, a few feet apart, for receiving the ends of stout wooden bars placed across the chimney, so as to form a sort of internal temporary ladder. By this means, and with the assistance of ropes and pulleys, all the building materials are hoisted as they are wanted. In this way, 1 bricklayer with the assistance of a labourer, can, in a few weeks, raise a chimney 40 feet high, 5 feet 8 inches square outside, 2 feet 8 inches inside at the base, 28 inches outside, and 20 inches inside at the top. The erection is facilitated, and the solidity increased, by building it in two or more successive plinths or recedures. Such chimneys must be thick and substantial near the base, in order to sustain the great heat of the fire, and prevent the hot current from cooling too rapidly. Dr. Ure says:—"When many flues are conducted into one chimney stalk, the area of the latter should be nearly equal to the sum of the areas of the former, or at least of as many of them as shall be going simultaneously. When the products of combustion from any furnace must be conducted downwards, in order to enter near the bottom of the main stalk, they will not flow off until the lowest part of the channel be heated, by burning some wood shavings or straw in it, whereby the air syphon is set going. Immediately after kindling this transient fire at that spot, the orifice must be shut by which it was introduced; otherwise the draught of the furnace would be seriously impeded. But this precaution is seldom necessary in great factories, where a certain degree of heat is always maintained in the flues, or at least, should be preserved by shutting the damper plate of each separate flue, whenever its own furnace ceases to act. Some chimneys are furnished at top with a coping of stone-slabs, to secure their brickwork against the infiltration of rains, and they should be furnished with metallic conducting rods, to protect them from explosions of lightning."[1]

At Mr. Thomas Cubitt's fine establishment at Thames-Bank, the chimney-shaft for the steam-engine is constructed in a peculiar manner. The chimney, which is circular, five feet in clear diameter all the way up, and 105 feet high, is built of very thin brickwork; that is to say, it is 14 inches thick at the bottom and 6 inches at the top; the bricks having been moulded for the purpose. It stands in the centre of a tower 17 feet square on the outside, formed of 14-inch walls all the way up, with hoop iron bond in the centre of the walls at certain intervals. The first tier of this bond is 15 feet from the ground; the other tiers are put closer together, as they approach the top. Around the shaft, but not touching it, are stone steps leading to the top, with landings at certain intervals. Mr. Cubitt's chief reason for adopting this mode of construction was to obtain a more picturesque landmark for his establishment than a chimney-shaft; but he is of opinion that its ultimate cost will be less than that of a shaft. It economises the fuel to a considerable extent by keeping off cold air; and moreover, a shaft would have required more expensive arrangements for erection than the shaft and tower. The surrounding tower does not touch the shaft at any point; and, on standing on the top landing, and pressing the hand with moderate force against the stalk, the whole of the shaft can be rocked backwards and forwards through a range of a few inches. This rocking doubtless takes place in all tall shafts by the action of the wind upon them. As the tower does not touch the chimney, the most perfect facilities are thus afforded for ascertaining the effect of heat upon this height of brickwork; and an index having been set up on the topmost landing, under cover, which is 80 feet from the ground, it is found that this length of shaft becomes five-eighths of an inch longer when the fire is lighted than it is when cold.[2] Two thermometers are inserted into the brickwork, the bulbs of which curve into the chimney, so that the temperature of the ascending current can be ascertained by inspection at two points, one 25 feet from the bottom, and the other 30 feet from the top. The following are a few of the data which have been collected by observing these instruments. They were furnished by Mr. Porter to the Editor during a recent visit to Mr. Cubitt's establishment.

The fire is lighted about 5 A.M.

	Lower Thermometer.	Upper Thermometer.	Temperature of air in the Tower		
5.30	210°	190°	78°	82	
7.30	261	208	76	82	
8 (Breakfast)	212	188	78	82	
8.30	240	200			
10.30	251	214			
12 (Dinner)	218	200			
12.30	180	110			
2	250	212	78	84	
2.30	260	223			Closed damper open. Water pressure $\frac{6}{10}$ths of an inch. Damper open 6 inches. Temperature in open air 55°.
3	260	216			
3.30	262	223			

CHINA-WARE, see POTTERY and PORCELAIN.

CHINTZ, a printed calico, in which figures of at least 5 different colours are printed on a white or light-coloured ground.

CHLORINE, a gaseous substance, (Cl. 35·5) discovered by Scheele, in 1774, but its elementary nature was first established by Davy in 1810, who proposed to abolish the unwieldly and inaccurate terms *dephlogisticated muriatic acid* and *oxymuriatic acid*, which

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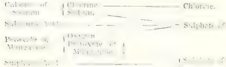
(1) Dictionary of Arts, Manufactures, &c. Our chief authorities in this article are Hood's Practical Treatise on Warming Buildings by Hot Water, &c. Second Edition, 1844. Dr Franklin's celebrated Letter on Chimneys, addressed to Dr Ingenhousz, 1785; and Tomlinson's Treatise on Warming and Ventilation, published in Weale's Rudimentary Series, 1850. [See WARMING and VENTILATION, and also APPENDIX.]

(2) The reader is aware that the application of heat to clay causes it to contract, by driving off the moisture. When the clay has been burned into bricks, it then expands by heat. Thus coke ovens expand considerably by heat. The stone coping of Waterloo Bridge expands and contracts so much by change of temperature as frequently to require pointing.

had been applied to it, and to substitute a name derived from its most striking physical quality, namely, its greenish yellow colour. The name chlorine (from χλωρὸς green), is now universally adopted.

Sea-salt (chloride of sodium) is the great natural source of chlorine. When required in large quantities for the purpose of the manufacturer, it is made by pouring diluted sulphuric acid on a mixture of common salt and oxide of manganese, contained in a large leaden vessel. [See BLEACHING.] The decomposition which ensues, will be understood from the following statement :—



Chlorine may also be readily procured by pouring strong muriatic acid upon finely powdered black oxide of manganese, contained in a retort or flask, and applying a gentle heat. The chemical changes which take place are as follows :—Muriatic, or as it is otherwise called, hydrochloric acid is a compound of chlorine and hydrogen: when this is mixed with a metallic protoxide, water and a chloride of the metal are produced; but when a peroxide, which contains twice as much oxygen as the protoxide, is used, a second portion of hydrochloric acid is decomposed by the oxygen in excess, which also unites with the hydrogen to form water, and the chlorine is set free.

Chlorine is very soluble in cold, but much less so in warm water. Hence it may be collected in bottles filled with water, at the temperature of not less than 90°, and inverted at the pneumatic trough: the stopples should be greased and inserted before the bottles are removed from the trough. Chlorine cannot be collected over mercury, as it combines at once with that metal. In the preparation of this gas, care must be taken not to allow it to escape in any quantity, as it is very suffocating, producing cough and irritation when inhaled only to a small extent. Its action, however, varies greatly with different individuals, and it is less irritating after the lungs have become accustomed to it by repeated use. When largely diluted with air, it is most pleasant and refreshing to many persons. Nevertheless extreme caution must be used in inhaling this gas in its most dilute form, and it should never be done as a remedial agent, except under medical advice.

Water at 60° absorbs about twice its volume of this gas, and acquires its colour and odour. By exposure to light, this solution is slowly changed by decomposition of water into hydrochloric acid, oxygen being at the same time liberated. Moist chlorine exposed to a temperature of 32°, forms yellow crystals of hydrate of chlorine.

The sp. gr. of chlorine is 2·47, and 100 cub. in. weigh between 77 and 78 grs. It condenses to a yellow limpid liquid, under a pressure of about four atmospheres.

Chlorine is a supporter of combustion, and has a very strong chemical attraction for hydrogen and the metals. A lighted taper plunged into this gas, burns with a dull red light: the hydrogen of the wax is alone consumed, the carbon being separated in the form of a dense black smoke. If a piece of paper wetted with oil of turpentine be immersed in a bottle of chlorine, it will burn, the hydrogen of the turpentine uniting with the chlorine, while the carbon is separated as an abundant soot. Phosphorus takes fire spontaneously in chlorine. Copper-leaf and powdered antimony also burn in the gas. A mixture of equal volumes of chlorine and hydrogen explodes on the application of flame or the electric spark, hydrochloric acid being the result. Such a mixture exposed to the direct rays of the sun, immediately explodes: the two gases combine slowly under the action of diffused daylight: but they undergo no change in the dark.

A most valuable and characteristic property of chlorine is its bleaching power; the most fixed organic colouring principles are instantly decomposed and destroyed by it: indigo, which resists the action of strong sulphuric acid, has its blue colour effectually destroyed by chlorine. Dry chlorine however does not bleach: hence the presence of water is always necessary to bring about these remarkable changes. [See BLEACHING.—PAPER.]

Chlorine is also the best and most powerful disinfectant. Unlike other substances used for fumigation, such as brown-paper, vinegar, scents, &c., which merely disguise the ill odours, or the mephitic atmosphere, chlorine absolutely destroys them. It is probable, that most ill odours, &c. are compounds of hydrogen; hence, the chlorine enters into combination with the hydrogen, forming muriatic acid, and the other substance, whatever it may be, to which the hydrogen communicated virulence, falls harmless. The use of chlorine as a disinfectant requires care. It should be used in the form of bleaching powder mixed with water, and exposed to the air in shallow vessels, if possible on a high shelf. The powder (chloride of lime) is gradually decomposed by the carbonic acid of the atmosphere, and the chlorine being evolved, falls slowly down, and is diffused through the room. If the action is required to be quicker, a little dilute muriatic acid may be allowed to drop into the vessel, by suspending a funnel with a piece of tow in the stem, over the vessel containing the bleaching powder. Another method is to suspend in the apartment, cloths steeped in a solution of the bleaching powder; or, in the absence of bleaching powder, the gas may be generated by one of the methods before described, care being taken to avoid excess. It must however be particularly borne in mind, that chlorine in any form must only be used as an aid to proper ventilation. It is a necessary condition of health, that our houses and rooms be properly ventilated: there is no substitute for ventilation, any more than for washing or for general cleanliness. Chlorine, like medicine, ought in general to be used on special occasions and under advice. In a sick-room, where proper ventilation is often difficult, chlorine liberated in very minute quantities will often be found singularly refreshing; but in this, as in all other cases of fumigation with chlorine, all metals, such as fender, fire-irons, &c., ought to be removed, for these become speedily tarnished by the action of chlorine.

When employed for disinfecting the wards of hospitals, &c., a pound of chloride of lime should be mixed with water in a hand-basin, and a pound measure of hydrochloric acid be poured upon it. The gas is evolved without heat. The persons concerned in the preparation of the materials, should tie a wet sponge over the nostrils, before going into the rooms.

There are several compounds of chlorine and oxygen, but the interest which attaches to them is chiefly scientific. Other compounds will be noticed under the names of the bases, [See Potassium—Sodium, *Chloride of;*] and the compound of chlorine and hydrogen is noticed under Hydrochloric Acid.

CHLOROFORM. The name of this substance has reference to the constitution of formic acid, which is represented by C_2HO_3: it is an oxide of a hydrocarbon (C_2H), to which the term *formyle* has been applied. Chloroform would be represented by C_2HCl_3, that is to say, it has the same composition as formic acid, in which 3 equivalents of chlorine have taken the place of 3 equivalents of oxygen. Chloroform may be obtained by distilling alcohol, wood-spirit or acetone with a solution of chloride of lime. 1 pint of hydrate of lime is suspended in 24 parts of cold water, and chlorine passed through the mixture until nearly all the lime is dissolved. A little more hydrate is then added to restore the alkaline reaction, the clear liquid mixed with 1 part alcohol or wood-spirit, and after 24 hours, cautiously distilled in a very large vessel. A watery liquid containing a little spirit, and a heavy oil, collect in the receiver; the latter, which is the chloroform, is agitated with water, digested with chloride of calcium, and rectified in a water-bath. It is a thin colourless liquid, of agreeable etherial odour, and sweetish taste. Its sp. gr. at 65° is 1.48; it is kindled with difficulty, and burns with a greenish flame. Its boiling point is about 142°; the density of its vapour is 4.2. When this vapour is inhaled, it induces insensibility more rapidly and effectually than ether vapour: hence its use in the performance of painful surgical operations. When a few drops of chloroform are placed on the hand, evaporation speedily goes on, and produces a great degree of cold. Professor Brande says, "When poured upon water, the greater part sinks in globules, which are of a milk-white appearance when the chloroform is not perfectly free from alcohol. It is so little soluble in water, that 3 drops added to 9 ounces of distilled water and well shaken, did not wholly disappear, although they imparted a strong odour to the liquid."

Chloroform is prepared on a large scale by cautiously distilling good commercial chloride of lime, water and alcohol. The whole product distils over with the first portions of water.

CHOCOLATE. This agreeable and nutritious substance was introduced into Europe from Mexico by the Spaniards, in 1520, and its source and mode of manufacture was by them long kept secret. Linnæus was so fond of chocolate that he gave the specific name of *Theobroma* (θεὸς and βρῶμα, the food of gods) to the cacao-tree which produced it. The Mexicans call the tree *chocolatl;* hence our word *chocolate* applied to the prepared seeds.

The *Theobroma Cacao*, or chocolate-nut-tree, Fig. 568, is a small tree, of which whole forests occur in Demerara. The Mexican cacao, however, is yielded by another member of this family. The capsules of the fruit of this tree are large, somewhat resembling a cucumber, and containing from twenty to thirty seeds, arranged in five regular rows, enveloped in a pulp, which has a sweet and not unpleasant taste, and is frequently used as food in places where the tree is grown. The trees are evergreen, and bear fruit and flowers all the year through; but the usual times for gathering the fruit are June and December. The fruit which is produced in the West India Islands, Berbice, and Demerara, is much smaller than that of South America. By far the largest quantity of seeds received in this country is from the West Indies, and of these the Trinidad nuts are considered the best.

Fig. 568. THE CHOCOLATE-NUT TREE.

The species of this tree are somewhat numerous, and the fruits thereof vary in size, form, and the number of the seeds which they contain. "The general number is from twenty-five to thirty in each fruit; being more abundant as well as of better quality in the cultivated than in the wild plants. They vary much in bitterness, and in the quantity of oil they yield, not only according to the species from which they are obtained, but the manner in which they are treated after being gathered and taken out of the pulpy fruit. In some instances they are buried in the earth in heaps, and allowed to ferment for thirty or forty days; a process which greatly improves them, and destroys the germinating power of the seed. The different kinds met with in commerce derive their names either from the place where they grow, or from some corruption of the native designation. The average size of good beans is that of a sweet almond, but somewhat thicker. The most esteemed of the known sorts is that termed *Soconuzco* or Mexican, with very small beans, with a remarkably fine flavour, and scarcely any acrid taste. These beans are always buried. This sort never comes to Europe. The next most valuable comes from the Esmeraldas, and has a very agreeable flavour: the chocolate prepared from it has a golden colour: it is seldom met with out of Mexico. The Guatemala cocoa consists of very large beans, very convex, often angular, and very much pointed at the one end. They contain much oil, and are mild, with a pleasant flavour. The beans from Guayaquil, which are three times as large as those of Soconuzco, are less prized than those of Guatemala. The Caracas or New Granada cocoa, which is among the more highly prized kinds that reach Europe, is obtained from the *Theobroma bicolor*, called by the natives Bacao, and cultivated at Carthago. The beans are of medium size, and very oily. But chocolate made of these alone is not very agreeable, and another kind is commonly mixed with them, which are much smaller and harder. Berbice cocoa beans are not unfrequently mingled with those of Granada. These are also smaller and thinner, but in other respects difficult to distinguish: the shell separates very easily from the kernel, which is reddish brown, and has a strong smell but a pleasant flavour. The Surinam and Essequibo cocoas are not unlike that from New Granada, but are harder, thicker, and not so sweet. All the foregoing are *earth-dried*, the following are called *sun-dried*, being merely collected in heaps and then turned over in the sun: they are consequently much cheaper. Brazilian, called also of Para, and of Maranham, is very extensively employed: the beans are small, smooth, long, somewhat flattened, externally reddish brown, with a bitter astringent taste: it is only worth half the amount of the former. The West Indian, called *Cocoa des Isles*, or *des Antilles*, is still less valuable, and is employed to form the low-priced cocoas and chocolates."[1]

According to Lampadius, the kernel of the West India cacao consists of:—

Fat oil	53.10
Azotized substances (theobromine)	16.70
Starch	10.91
Gum and colouring matter[1]	9.76
Lignine	0.90
Water and loss	8.63
	100.00

The substance named *theobromine* is white, pulverulent, and of a bitter taste, resembling *caffeine*. [See COFFEE.] It is sparingly soluble in hot water, and but little soluble in alcohol or ether.

The fruit of the cacao, like almonds, is covered with a thin skin or husk, which forms about 12 per cent. of the weight of the beans: it contains no fat, but, in addition to lignine or woody fibre, which forms half its weight, it yields a light brown mucilaginous extract by boiling in water. This husk or shell is known to the manufacturers of chocolate under the name of *cocoa, miserable*, or *destitute*. The demand for this article in Ireland is so great that in one year as much as 612,122lbs. of *shells* have been consumed, and only 4000lbs. of the nut.

The following is Dr. Ure's analysis of Guayaquil cocoa:—

Concrete fat or butter of cocao dissolved out by ether	37
Brown extractive, got out by hot water after the operation of ether	10
Ligneous matter, with some albumine	30
Shells	14
Water	6
Loss	3
	100

The *butter of cacao*, or fatty matter of the nut, is of the consistence of tallow, of a white colour, and of a mild agreeable taste. It is not apt to become rancid by keeping. It is said to be very nutritious, and to act as an anodyne. It is particularly recommended for making ointments. Its proportion, as well as that of the other ingredients, varies greatly in the different sorts, as will be seen by comparing the above analyses. The West India kinds contain more of the butter than those from New Granada. It is therefore more advantageous to employ the latter in the manufacture of chocolate, and the former for extracting the solid oil for the manufacture of candles, soap, or pomades. The oil can be obtained by exposing the beans to strong pressure in canvass bags, after steaming, or soaking them some time in boiling water. 1lb. of cacao gives from 5 to 6 ounces of the butter: it has a reddish tinge at first, but becomes perfectly white by long boiling in water. This oil contains a large proportion of stearine, and is therefore solid at ordinary temperatures: it melts at 122°. It is soluble in boiling alcohol, but precipitates in cold. It is perfectly soluble in ether, which thus furnishes an easy method of detecting adulteration with beef-fat, suet, marrow, almond oil, wax, &c. It is less employed in this country than in France. A soap made with it and soda is an agreeable toilet article for those who are troubled with a rough harsh skin or chapped hands.[2]

The manufactured article, chocolate, is made to assume a variety of forms, to which various names are attached, according to the object proposed by the mode of manufacture. We will confine our attention chiefly to three forms, namely, chocolate *nibs*, *soluble* chocolate, and *chocolate*, properly so called, and lastly, *flake cocoa*.

The beans are received in bags, weighing from 1½ to 2 cwt. each, and the first process is to pick them,

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(1) Penny Cyclopædia, Art. *Theobroma*.

(1) The colouring matter, amounting to 2 [illegible], is a reddish dye-stuff, [illegible] cochineal.

(2) The soap and candles prepared from *cocoa-nut oil* have nothing to do with the article now under consideration. Cocoa-nut oil is obtained from the *Cocos nucifera*.

for the purpose of separating any spoiled or mouldy portions. They are then gently roasted over a fire in an iron cylinder, provided with openings at the ends to allow the vapours to escape. The heat is first applied very slowly, in order to dissipate the moisture: a quick fire is injurious, as it hardens the surface. When the aroma begins to be well developed, the beans are turned out into shallow wooden coolers, and moved about every now and then with wooden rakes with long handles. There is a loss of 8lbs. or 9lbs. per cwt. in roasting. When quite cold, the beans are broken down in a hand-mill to the size of common split beans, and the shells (or *destitute*) are separated by a winnowing or corn-dressing machine.

The cocoa-nibs thus prepared are sold as an article of food; but they require two hours' boiling, as the inner seed-coat passes down into the substance of the cotyledons, rendering the prolonged application of heat and moisture necessary to dissolve the contents.

For making chocolate the roasted and crushed nut, entirely divested of its shell, is submitted to the grinding action of two horizontal mill-stones surrounded by a steam jacket, which raises them to a temperature of upwards of 200°. The top stone is the runner. The nibs are put into a hopper, from which they gradually descend down a shoot, the end of which touches in succession four leaves raised on the vertical axis which gives motion to the runner: by this means a shaking motion is given to the shoot, and the nibs are thus made to fall down in a gradual manner. The heat, the pressure, and the friction of the stones, reduces the nibs to a paste, and liberating the oil or butter of cacao renders it fluid. Escaping at the junction of the two stones, this fluid paste issues at an opening made for it at the side, (see Fig. 569,) where it is received by a shoot, and is conveyed to a second pair of mill-stones situated at a lower level, and similarly heated by means of a jacket of steam. The stones are here set closer together than in the first pair, and by their action, all hard and gritty particles of the nut which escaped in the first grinding are broken down, and the paste flows down the shoot of the second pair of stones as a smooth shining equable fluid: it is received into a pan, where in cooling it solidifies into a hard cake.

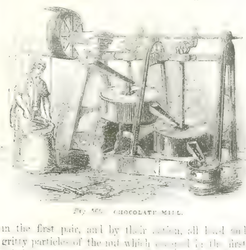

Fig. 569. CHOCOLATE MILL.

In this state the bean will not form an emulsion with water, on account of the large proportion of concrete fat contained in it: to fit it for this purpose some additional substance must be introduced, to assist this emulsive union of the fat with water. Sugar, honey, treacle, gum, starch, flour, rice, and arrow-root, are well adapted for this purpose. On the Continent, vanilla, cinnamon, cloves, long-pepper, musk, or other perfume, are frequently added, but this is for making a fancy rather than a useful article.

For the purpose of mixing the different ingredients with the ground bean, the honey, treacle, arrow-root, &c., being reduced to the fluid state in large mixing pans of tinned copper heated by being surrounded by steam jackets, the ground bean is added in the proper proportion, and the whole well incorporated at the temperature which experience has determined to be the best. While still thin with the heat and agitation, the chocolate is poured into tin moulds arranged in a wooden tray, and quickly removed to a cool place where they are exposed to a draught of air. The moulds must be well shaken to insure the filling up of all the cavities, to give a sharp and polished impression, and to indent clearly those lines which divide the cake of chocolate into 8 equal parts, each part weighing a quarter of an ounce, the proper quantity for making a cup of chocolate, although the directions say two of the divisions or half an ounce. Care and experience are required in regulating temperature, for if the chocolate be introduced into the moulds too hot it will have a damp dull surface; and if not hot enough, it will not take the proper form. The tin moulds after the cakes are removed from them, are in a highly electric state, and will attract and repel light bodies. Of course the cakes are in an opposite electrical state. The difference between soluble chocolate and chocolate that requires boiling, *(Sir Hans Sloane's chocolate,* for example,) is that, in the former case, the materials, honey, sugar, &c., added to the nut and minutely incorporated therewith, are all very soluble in water, while in the latter case, the added materials are not soluble without the assistance of boiling heat and continued stirring.

When a paste instead of a hard cake is desired, the ground bean is mixed with some fluid soluble substance, such as treacle. Some of the inferior kinds, both cake and paste, as made by the lower class of manufacturers, are adulterated with hog's lard or sago, and some cheap colouring matter. When chocolate contains much starch it forms a pasty mass with boiling water.

The confectioners of Paris make a variety of sweetmeats of chocolate and sugar, which may be eaten without further preparation. This is the *chocolat de santé*. The perfumed sorts are consumed in enormous quantities in France, Italy, and Spain. In Britain, simple chocolate is preferred, and is, perhaps, the best substitute for tea and coffee. It sometimes produces a sense of heaviness in the stomach, resembling slight repletion, and occasioning head-ache. This generally arises from using too much chocolate in preparing the beverage. It is stated that the Spaniards do not consider chocolate to be very nutritious: priests who are required to fast many hours before saying mass, are nevertheless allowed to drink chocolate.

Cocoa is a cheap substitute for chocolate, and is distinguished therefrom by containing a certain proportion of the shell or destitute. The nut as it leaves the grindstones is broken up, mixed with the shell and also with a quantity of farinaceous, saccharine, and other matters, all cheaper than the chocolate nut. If powdered cocoa is to be produced, the whole of these materials are kneaded together into a solid cake, which is dried and afterwards reduced to powder by pressing the cake up against a series of revolving cutting knives: the powder is then finished and is packed up in paper for sale. But if flake cocoa be required, the powdered mixture is passed through 3 or 4 steel mills gradually increasing in fineness, the effect of which is so to combine and condense the materials, assisted by the presence of the oil of the nut, that they form into *flakes*, in which state they are ready for use. The flakes are best formed when the mills become slightly heated by the continued friction of the materials passing through them.

Fig. [illegible] [illegible] MILLS.

In the year 1860, there were imported into this country 9,009,839 lbs. of cocoa, of which quantity 3,481,463 lbs. were retained for home consumption, the remainder being re-exported. In 1858, the quantity imported was 10,338,404 lbs. Before the alteration in the tariff in 1842, the duty on cocoa from British possessions was 2*d.*, and from foreign countries 6*d.* per lb.; these were reduced to 1*d.* and 4*d.* On husks and shells the duty was ½*d.* and 1*d.*: these were left unaltered. On cocoa paste and chocolate which was 4*d.* per lb. from British possessions, and 4*s.* 4*d.* from foreign, the duty was reduced to 2*d.* and 6*d.*[1]

CHOKE-DAMP, a term given by the miners to carbonic acid gas, the product of the combustion of the small coal, dust, &c., after an explosion in a coal pit. See COAL.

CHROMIUM, a metal discovered by Vauquelin in 1797, and named from *χρῶμα*, *colour*, on account of its tendency to produce coloured compounds. Its two native combinations are the chromate of lead, and the chromite of iron. The latter, a compound of the oxides of chromium and iron, is found in the Shetland isles, Unst and Fetlar; near Portsoy in Banffshire, in the department of Var in France, (but this source is nearly exhausted;) in Silesia and Bohemia, and also at the Bare Hills near Baltimore, in Maryland. The chief use of this ore is for the production of chromate of potash.

Metallic chromium may be obtained by intensely heating the oxide with about one-tenth of its weight of powdered charcoal; but the reduction is imperfect. Dumas describes chromium as being like platinum in colour; it scratches glass, and takes a good polish. Its density is 6·81. When pure it is probably magnetic: its salts are distinctly so. (Symbol $Cr = 26{\cdot}27$.)

As many as five oxides of chromium have been enumerated. The *protoxide* ($Cr\,O$) does not appear to be a very staple compound. The *sesquioxide* (Cr_2O_3) or *green oxide* is formed by the decomposition of chromate of mercury by ignition: this yields a very pure oxide. There are various other methods of producing this oxide. (Professor Brande enumerates nine.) This oxide is infusible, and unchanged by heat, but the shades of its green colour are deeper in proportion to the temperature to which it has been exposed. When fused with borax and other vitrifiable substances, it confers on them a characteristic emerald green colour, and hence its use in porcelain and enamel painting. A *hydrate* of this oxide may be formed by precipitating it from its acid solutions by the caustic fixed alkalies. It falls as a bulky green powder, slightly soluble in excess of the alkali, but is thrown down on boiling the solution. Native sesquioxide of chromium has been found in the form of a green incrustation in the department of the Rhone in France. It is the colouring matter of the emerald, and occurs in a few other minerals, such as diallage and serpentine. It is associated with silica and alumina: the shades of green varying with the amount of the oxide; but the richest specimen does not contain more than 13 per cent. *Binoxide of chromium* ($Cr\,O_2$) is formed when nitrate of chromium is decomposed at a dull red heat. It is of a brown colour. *Peroxide of chromium* ($Cr\,O_3$) is an important and beautiful acid, the *chromic*. There are various methods of preparing it, but it may be stated that whenever oxide of chromium is strongly heated with an alkali in contact with air, oxygen is absorbed, and chromic acid generated. The acid nearly pure may be obtained by the following simple process described by Mr. Warington:—100 measures of a cold saturated solution of bichromate of potash are mixed with from 120 to 150 measures of concentrated sulphuric acid, (free from lead,) and the whole suffered to cool. The chromic acid crystallizes in brilliant crimson-red prisms. The mother liquor is poured off, and the crystals placed upon a thick flat tile of biscuit porcelain to drain, being closely covered by a glass or bell-jar, or another tile may be placed on the crystals, and the whole submitted to pressure for a considerable time. On removing the chromic acid it will be found to be dry, and with scarcely a trace of sulphuric acid.

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(1) For the illustration and [illegible] of the information in this article, as well as in the [illegible] CHOCOLATE and COFFEE, we are indebted to Messrs Barry, [illegible] Street, London.

Chromic acid is of a beautiful red colour at the ordinary temperature, but it becomes almost black by being heated. Its solution is of a deep yellow brown; its taste sour and metallic; it tinges the skin yellow. At a red heat it gives out oxygen, and sesquioxide remains; it is acted on with energy by ammonia, and converted into oxide. It dissolves in alcohol, and the solution gradually deposits green oxide. It is a powerful oxidising and bleaching agent, yielding half its oxygen to oxidisable bodies, and being reduced thereby to sesquioxide.[1] Hence it can be successfully used in calico-printing, where the more powerful chlorine would be objectionable. Chromic acid is very deliquescent and soluble in water. The solution is decomposed by the sun's rays, and oxide thrown down. In combination with oxide of tin, this acid (or oxide of chromium) forms a pink colour used in porcelain painting. Chromic acid is said to be the colouring matter of the ruby.

The three most important compounds of chromic acid in the arts, are the *chromate* and *bichromate of potash*, and the *chromate of lead*. Chromate of potash (KO,CrO_3) is the source of all the preparations of chromium in the arts. It is made directly from the native chrome iron ore, by reducing the stone to powder, mixing it with one fourth of nitre, and exposing the mixture to a strong heat during several hours. The soluble matter is then washed out, and the process is repeated until the ore is decomposed. The washings yield chromate of potash by evaporation. The crystals are of the same yellow colour as the solution. 100 parts of chromate of potash contain 48 of potash and 52 of chromic acid. This salt has a cool, bitter, and disagreeable taste. It is very soluble in boiling water. At 60°, 100 parts of water dissolve about 48 of the salt; or in other words, it is soluble in 2 parts water at 60°. Its colouring power is so great that 1 part gives colour to 40,000 parts of water. When heated to 100° it becomes crimson, but regains its yellow colour on cooling. As chromate of potash is isomorphous with sulphate of potash, the latter salt is sometimes used to adulterate the former. The adulteration may be detected by adding a few drops of nitric acid to the solution of the chromate, and then on testing with nitrate of baryta, an insoluble sulphate of baryta is thrown down.

When sulphuric acid in proper quantity is added to a solution of chromate of potash, one-half of the base is removed, and the neutral chromate is converted into bichromate ($KO,2CrO_3$). There is some difficulty in separating the sulphate from the bichromate, hence it is desirable to use nitric or acetic acid instead of sulphuric. Immense quantities of this salt are manufactured at Glasgow for the use of the calico-printers. It crystallizes by slow evaporation in beautiful red tabular crystals, derived from an oblique rhombic prism. It melts when heated; it is soluble in 10 parts of water at 60°, but is much more soluble in boiling water. The solution has an acid reaction. Solutions both of the chromate and bichromate of potash have powerful antiseptic properties; but they have an injurious action on the system when brought much in contact with the skin, causing painful sores which are difficult to heal. Paper impregnated with these salts and dried, forms excellent tinder. 100 parts of bichromate of potash contain 31.6 of potash, and 68.4 of chromic acid.

On mixing a solution of chromate or bichromate of potash with nitrate or acetate of lead, a brilliant yellow precipitate falls, which is chromate of lead (PbO,CrO_3), or *chrome yellow* of the painter. It consists in 100 parts of 68.29 oxide of lead, and 31.71 chromic acid. On boiling this compound with lime-water, one-half of the acid is withdrawn, and a subchromate of an orange red colour is left. The subchromate is also formed by adding chromate of lead to fused nitre, and then dissolving out the soluble salts with water. The product is crystalline, and in beauty of tint rivals vermilion. The yellow and orange chrome colours are fixed upon cloth by the alternate application of the two solutions, and in the latter case by passing the dyed stuff through boiling hot lime-water. Chromate of lead is insoluble in water, but soluble in nitric acid and in solution of potash. It forms, with solution of carbonate of potash, carbonate of lead and chromate of potash. With hydrochloric acid it forms chloride of lead and a hydrochloric solution of chromic acid. Heated in concentrated hydrochloric acid, chlorine is given off, and chloride of lead and a green solution containing chloride of chromium are formed. When this salt is heated its colour deepens. It fuses at a red heat, and gives off oxygen. A native chromate of lead has been found in the gold mine of Beresof in Siberia. A dichromate or subchromate of lead ($2PbO,CrO_3$), an insoluble scarlet-coloured powder, is also used with the former, both in oil and water colours, in dyeing and calico-printing. These salts are often adulterated with sulphate of lead and sulphate of lime.

A salt of chromic acid is recognised by its behaviour with solutions of baryta and lead; and also by its colour and capability of furnishing by deoxidation the green oxide of chromium.

CHRONOMETER, see Horology.

CHURN, see Butter.

CIDER. The expressed and fermented juice of apples, a liquor made in large quantities in England and Ireland, and in the north of France. The machinery employed is generally of a very rude kind. A large circular stone trough called a *chase*, receives the apples, which are crushed therein by the action of a heavy circular stone called a *runner*, turned by horse-power. The crushing is carried on till not only the apples but the very pips are broken. The pulp, called *must*, is then transferred to the cider-press, where it is subjected to heavy pressure between hair-cloths, or layers of reed-straw, and the cider exudes in the form of a thick brown juice, leaving only a dry residue between the hair-cloths. But this dry must is sometimes steeped in water and ground over again, from which a thin water-cider is produced. As the cider is pressed from the hair-cloths, it passes along a channel in the frame of the press into a flat tub called a *trin*, whence it is transferred at once into casks placed out of doors, or in a cool shed. In a few days it will ferment, the thicker portions subsiding, and the rest becoming clear and bright. It is then usually racked off, and the sediment strained through linen bags. If fermentation continues, and is in excess, the cider has to be racked off several times. If fermentation is too slow, and the liquor remain thick, isinglass or eggs stirred into it may clear it, but do not always have that effect. The total produce of cider and *perry* (the latter made in the same way from the pear) is estimated at from 150,000 to 160,000 barrels annually. The duty, which amounted to 10*s.* a barrel, was repealed in 1830.

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[1] If a few drops of absolute alcohol be allowed to fall on chromic acid, the latter is suddenly converted into sesquioxide with such a development of heat as to kindle the alcohol.

CIGARS, see TOBACCO.

CINNABAR, the sulphuret of mercury, and the principal ore of this metal. See MERCURY.

CINNAMON, the bark of the cinnamon-tree, *Laurus cinnamomum*, a native of Ceylon. It also grows in Cochin China. In its natural state it attains the height of 20 or 30 feet, sending forth spreading branches clothed with thick foliage. The leaf somewhat resembles that of the bay, but is longer and narrower. The flowers bloom in January, and resemble in size and shape those of the lilac. These are followed by one-seeded berries of the shape of an acorn, but not so large as a common pea. This fruit yields, by being boiled, an oil, which cools into a wax-like substance, and is used for making candles; these emit an agreeable odour, and in the kingdom of Candy are reserved for the sole use of the court.

Cordiner in his history of Ceylon[1] states a number of interesting particulars respecting this tree. The cultivated trees are not allowed to rise higher than about 10 feet. When the trees first put forth their flame-coloured leaves and delicate blossoms, the effect is very beautiful. In 3 years after planting, each tree affords 1 shoot fit for cutting; at the 5th year, from 3 to 5 shoots; and after 8 years it yields as many as 10 branches of an inch in thickness, fit for cutting. From the ages of 10 to 12 years is the period of its greatest perfection; but its duration is not limited, as the root spreads and every year sends up new shoots or suckers. The tree is known to be in the best state when the bark separates easily from the wood, and the inside is covered with a mucilaginous juice, which it is necessary to remove. The shoots are cut when from half to three-quarters of an inch in thickness, and in lengths of from 2 to 3 feet. Each man is compelled to furnish a certain quantity of sticks, and having completed his task, he conveys his fragrant load to a shed, where the bark is stripped from the wood and the epidermis scraped off. During this process the diffused fragrance is said to be delightful, but in other parts of the plantation the peculiar smell of cinnamon cannot be distinguished unless the trees be violently shaken. The wood deprived of the bark has no smell, and is used as fuel. The cleansed bark is of a pale yellow colour, and of about the thickness of parchment. It is placed on mats to dry in the sun, when it curls up and acquires a darker tint. The smaller pieces are then put inside the larger, and the whole close together into the tubular form in which it is sold in the shops. When the rind or part forming the cinnamon is first taken from the tree, it is said to consist of an outer portion which tastes like common bark, and an inner portion which is very sweet and aromatic. In the course of drying, the oil of the inner portion, on which the flavour depends, is communicated to the whole, and the quality of the entire bark is said to depend upon the relative quantities of those portions of the bark. The cinnamon of Ceylon has the outer portion much thinner in proportion to the inner than the cassia[2] of other countries; and to that its higher pungency is attributed. According to McCulloch cinnamon is imported in bags or bales, weighing 92½lbs. each, and in stowing it black pepper is mixed with the bales to preserve the cinnamon. The best cinnamon is thin and rather pliable, of a light yellow colour, smooth and shining, with a splintery fracture, an agreeable, warm, aromatic flavour, and a mild sweetish taste; when chewed the pieces become soft and seem to melt in the mouth; it may be borne on the tongue without pain, and is not succeeded by any after taste. The cinnamon of Cochin China is preferred in China to that of Ceylon: the annual imports into Canton and other parts, vary from 250,000 to 300,000lbs. There are ten varieties of this species in the market: it is not cured like that of Ceylon by freeing it from the epidermis. In 1857, the quantity of cinnamon imported into the United Kingdom was 745,316lbs., of which only 39,344 lbs. were retained for home consumption. In 1858, 651,056lbs. were imported. The duty by the new tariff is 6*d.* per lb. on foreign, and 3*d.* per lb. on the cinnamon of British possessions.

Oil of cinnamon was formerly obtained at Columbo by distilling with water the fragments of the cinnamon bark broken off in packing, and also the coarse cinnamon unfit for exportation. A very small quantity is contained in the bark, 300lbs. of which are required to yield 24 ounces of oil. At present there are two varieties of oil of cinnamon met with in commerce, of very unequal value, viz. that of China and that of Ceylon: the former is considered the best, but both are very impure. The pure oil may be extracted from them by adding cold, strong nitric acid: the crystalline matter which forms after the lapse of a few hours, separated and decomposed by water, yields pure oil of cinnamon. When the oil is made from the finest cinnamon its specific gravity is said to be greater than water, but from the coarse sort, less. In the former case fine cinnamon is crushed, infused twelve hours in a saturated solution

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(1) Quoted, [illegible], by Dr. Lankester, in his work on "Vegetable Substances used for the Food of Man," published in the Library of Entertaining Knowledge, [illegible] in the early part of this century.

(2) The *laurus cassia* is chiefly brought from China: the bark and buds are known in commerce as *cassia lignea* and *cassia buds*: they have the same aroma, though in an inferior degree, as cinnamon, and are extensively substituted for it.

of common salt, and then the whole is subjected to rapid distillation. Water passes over, milky, from the presence of essential oil, which after a time separates and sinks to the bottom of the receiver. It is collected and left for a short time in contact with chloride of calcium. Like most of the volatile oils, it has a certain degree of solubility in water: it is highly fragrant, colourless or of a slight yellow tint, of an agreeable cinnamon odour, and of a pungent burning flavour. It contains according to Dumas $C_{18}H_8O_2$.

When the pure oil is exposed to the air it absorbs oxygen, and becomes converted into a mass of white crystalline matter, which is *hydrated cinnamic acid.* Cinnamic acid is found in Peruvian and Tolu balsams, associated with benzoic acid which it closely resembles, and certain oily and resinous substances. The radical of this acid has been named *cinnamyle;* it has not been isolated. The following is a list of cinnamyle compounds:—

Cinnamyle, symbol Ci	$C_{18}H_7O_2$
Hydride of cinnamyle; oil of cinnamon	$C_{18}H_7O_2 + H$
Oxide of cinnamyle, cinnamic acid	$C_{18}H_7O_2 + O$
Chloride of cinnamyle	$C_{18}H_7O_2 + Cl$

CITRIC ACID, an acid common to many vegetables; it is abundant in lemon and in lime juice; it is also contained in currants, gooseberries, raspberries, and strawberries, and in the onion and potato. It is prepared by a few manufacturers on a very large scale for the use of calico-printers: it is also used in pharmacy. It is obtained chiefly from lemon and lime juice, a gallon of good lemon juice affording about 8 ounces of the crystallized acid, although as much as 12 ounces have been obtained from this quantity of juice. In preparing the acid, the juice is allowed to ferment a short time, for the purpose of separating mucilage and other impurities; the clear liquor is then saturated with chalk, added in small portions at a time, which forms with the citric acid an insoluble compound. This is washed with hot water, decomposed by the proper quantity of sulphuric acid diluted with water, and the filtered solution evaporated to a small bulk is left to crystallize.

The product is drained from the mother liquor, re-dissolved, digested with animal charcoal, and again concentrated to the point of crystallization. Citric acid forms colourless prismatic crystals, which have a pure and agreeable acid taste: they dissolve readily in water, but the solution becomes mouldy by long keeping. Citric acid is sometimes adulterated with tartaric acid, which may be detected by adding to the acid, dissolved in cold water, a solution of acetate of potash, which will throw down a white crystalline precipitate of bitartrate of potash (cream of tartar), if tartaric acid be present. Citric acid is distinguished from most of the other vegetable acids by its behaviour with lime-water: when citric acid is added to lime-water, the liquid remains clear till it is heated, and then becomes turbid, and deposits citrate of lime.

"Citric acid is tribasic: its formula, in the gently-dried and anhydrous silver-salt, is $C_{12}H_5O_{11}$. The hydrated acid crystallizes with two different quantities of water, assuming two different forms. The crystals which separate by spontaneous evaporation from a cold saturated solution contain $C_{12}H_5O_{11}, 3HO + 2HO$, the last being water of crystallization; while, on the other hand, those which are deposited from a hot solution contain but 4 equivalents of water altogether, 3 of which are basic. Citric acid is entirely decomposed when heated with sulphuric and nitric acids: the latter converts it into oxalic acid. Caustic potash at a high temperature resolves it into acetic and oxalic acids. The citrates are very numerous, the acid forming, like ordinary phosphoric acid, three classes of salts, which contain respectively 3 equivalents of a metallic oxide, 2 eq. of oxide and 1 eq. of basic water, and 1 eq. oxide and 2 eq. basic water, besides two sub-salts, in which the water of crystallization is perhaps replaced by a metallic oxide."[1]

CIVET, a substance used in perfumery, having a powerful scent, resembling musk and ambergris. It is obtained from the civets (*Viverra*), a genus of carnivorous animals, approaching nearest in their form and habits to the fox and the cat. But the distinctive character of the civets consists in an opening near the tail, leading into a double cavity of considerable size, furnished with glands for the secretion of the odorous substance. When the secretion is in excess, the animal frees itself from it by a contractile movement, which causes the civet to ooze from the bag. This is carefully collected and sold (not without adulteration with butter or oil, to increase its weight) at a very high price. These animals are carefully kept and tended in North Africa, for the sake of the perfume: they are also common in South America, and in the forests of Japan. Civet contains free ammonia, resin, fat, and extractiform matter, and a volatile oil to which its odoriferous properties are due. It is imported into England from the Brazils and from Guinea. When genuine, it is worth from 30 to 40 shillings an ounce.

CLAY, a compound, or perhaps only a mixture, of the two earths, alumina and silica, with water. Clay is an essential ingredient in all fertile soils. Its origin is thus explained by Mr. Fownes: "Silicates of alumina enter into the composition of a number of crystallized minerals, among which felspar occupies, by reason of its abundant occurrence, a prominent place. Granite, porphyry, trachyte, and other ancient unstratified rocks, consist in great part of this mineral, which, under peculiar circumstances, by no means well understood, suffers complete decomposition, being converted into a soft friable mass of earthy matter. This is the origin of clay: the change itself is seen in great perfection in certain districts of Devonshire and Cornwall; the felspar of the fine white granite of those localities being often disintegrated to an extraordinary depth, and the rock altered to a substance resembling soft mortar. By washing, this finely-divided matter is separated from the quartz and mica, and the milk-like liquid being collected in tanks and suffered to stand, deposits the suspended clay, which is dried, first in the air, and afterwards in a stove, and employed in the manufacture of porcelain.[1] The composition assigned to unaltered felspar is $Al_2O_3, 3SiO_3+KO,SiO_3$, or alum, having silicic acid in the place of sulphuric. The exact nature of the change by which it passes into porcelain clay is unknown, although it evidently consists in the abstraction of silica and alkali. When the decomposing rock contains oxide of iron, the clay produced is coloured. The different varieties of shale and slate result from the alteration of ancient clay beds, apparently, in many instances, by the infiltration of water holding silica in solution: the dark appearance of some of these deposits is due to bituminous matter." [See ALUM and ALUMINA.]

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[1] Fownes, "Manual of Chemistry."

According to Gmelin, nearly all pure clay consists of $Al_2O_3, 2\,SiO_2+2\,Aq.$; but in nature it is generally found mixed with carbonate of lime, magnesia, and protoxide of iron, which cause it to effervesce with acids; it also contains manganese, finely-divided quartz, felspar, mica, organic matter, &c., all of which modify its properties and applications to a considerable extent. The presence of potash, lime, sesquioxide of iron, &c., renders it more fusible. Pure clay is soft, more or less unctuous to the touch, white, and opaque, and emits a characteristic odour when breathed upon. This odour has been referred to ammonia contained in the clay. Clay is converted by water into a doughy mass, of various degrees of tenacity, but it loses this quality on drying. When rapidly heated it cracks in every direction, but when slowly heated it parts with its water at a temperature below redness; and at the same time diminishes in bulk: if heated to redness, it continues porous, and may be saturated with water; but it no longer falls to pieces when put into water. The stronger the heat to which it is exposed, the more hard, dense, and sonorous does the clay become. At a very high temperature, the pores contract; but the specific gravity of the clay, taken in a state of powder, increases only up to a dull red heat: at a higher temperature it again diminishes. Pure clay does not fuse in the most powerful blast-furnaces; it becomes, however, soft enough to be bent for pipe-stems. Clay dissolves with difficulty in borax, forming a transparent glass; with phosphate of soda it forms a glass which is transparent and white while hot, and becomes opalescent as it cools, a skeleton of silica being also separated; with carbonate of soda it forms a green glass, if iron be also present; ignited with solution of cobalt it generally assumes a blue colour. Clay does not dissolve in dilute muriatic or nitric acid. The action of sulphuric acid has been already referred to in our article on ALUM.

The property which clay possesses of being converted by heat into a strong mass, which no longer falls to pieces in water, is taken advantage of in the manufacture of bricks and vessels of various kinds. To diminish its contraction in drying and burning, it is generally mixed with a considerable quantity of quartz, sand, or with powder of burnt clay. The smaller the amount of lime, potash, &c., present in the clay, the higher is the temperature which it sustains without fusing, and the more dense and solid is the baked mass obtained. But since it always remains porous, it is generally covered with a glaze consisting of an easily fusible glass, usually containing oxide of lead. For stoneware and porcelain a mixture is used of very infusible clay and fine quartz sand, with a certain portion of gypsum or felspar. The lime present in the former, or the potash in the latter, gives rise at a high temperature to incipient fusion and softening of the mass, by which means its porosity is in a great measure diminished.[2] [See POTTERY and PORCELAIN.]

The following are some of the common varieties of clay:—1. *Pipe-clay.* This is of a greyish white colour, with an earthy fracture, and a smooth greasy feel; it adheres to the tongue, and is very plastic, tenacious and infusible. When burnt it is of a cream colour, and is used for tobacco-pipes and white pottery. It is found near Poole in Dorsetshire. 2. *Potter's clay* is of various colours, chiefly reddish or grey, and becomes red when heated. Mixed with sand it is formed into bricks and tiles. It is found in Hampshire, Berkshire, and Devonshire, and is forwarded from thence in large quantities to the Staffordshire Potteries. 3. *Stourbridge clay* resembles potter's clay to a certain extent, but is far more refractory in the fire. It is of a dark colour, owing probably to the presence of carbonaceous matter. It is extensively used in making crucibles, glass pots, &c. 4. *Brick-clay* or *loam* is found in abundance on the London clay, and frequently rests on an interposed bed of sand. It varies greatly in appearance, texture and composition; its colour depending on the proportion of oxide of iron contained in it. 5. *London clay* is a very extensive deposit of a bluish clay. Near the surface, however, it has often the usual clay colour. It extends over the greater part of Middlesex, the whole of Essex and Suffolk, and part of Norfolk. It frequently rises almost to the surface. The lower beds are sometimes yellowish, white, or variegated. This clay contains organic remains. 6. *Plastic clay* skirts the London clay within the London chalk basin, and it appears also at the Isle of Wight. This formation comprises a variable number of sand, clay, and pebble beds, alternating irregularly, and lying immediately upon the chalk. The sand-beds of this formation supply the deep wells in and about London with soft water. [See ARTESIAN WELLS.]

Brongniart in his "Traité des Arts Céramiques ou des Poteries," (Paris, 1844,) has given an elaborate list of clays used in the arts in different parts of the world. The number of specimens cited is 167. Their physical and chemical characters, composition, locality, and application are also given. We shall refer more particularly to this work in the article POTTERY AND PORCELAIN.

CLOCK. See HOROLOGY.

CLOVES, the unopened flowers of the clove-tree,

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(1) This forms the *Kaolin*, to which the porcelain of China owes its celebrity.

(2) Gmelin's "Handbook of Chemistry." Translated by Henry Watts. Vol. III. London, 1849. Published by the Cavendish Society.

(*Caryophyllus aromaticus*,) a native of the Moluccas, aromatic in its bark, root, leaves, and flowers, but with an insipid fruit resembling a small plum. Vigorous trees yield 10 or 12 pounds weight of flowers annually. The largest trees (which are as much as 8 feet in diameter) sometimes yield 50 or 60 pounds weight. Cloves as imported are nearly black, of a powerful fragrance, and hot acrid taste. They derive their name from *clou*, the French for a *nail*, owing to the resemblance they are thought to bear in their dried state to small nails. They are imported from the Dutch settlements, the best in chests, the inferior sort in bags. The Dutch have exclusive possession of the Moluccas or Clove islands, and by a short-sighted policy, they have limited the cultivation of these trees to one island, Amboyna, the seat of their power, and send an annual fleet to visit the other islands, and suppress the growth of cloves, which spring up like weeds in the soil. This arises from a jealous apprehension lest the natives should interfere with their policy, which is to derive a large profit from a small trade, instead of a moderate profit from a more extended and beneficial one. Now that the duty has been almost taken off cloves, (being reduced to sixpence a pound,) the consumption has considerably increased, but not in the proportion which it would have done under a more liberal policy. The price of cloves in the London market, exclusive of the duty, varies from 1s. to 2s. 2*d*. per lb. In 1860, 981,308 lbs. of cloves were imported, and in 1859, 727,519 lbs. of which 272,822 lbs. were entered for home consumption.

An essential oil is obtained from cloves by repeated distillation, and it is a common trick to mix cloves thus deprived of their oil with other cloves. They may easily be detected by being lighter coloured, shrivelled, and without the knob. Oil of cloves is hot and fiery. It is used in medicine as a stomachic, and to render some medicines safer and more agreeable. Two drops form a dose.

The sp. gr. of oil of cloves varies between 1.05 and 1.06, so that it is heavier than water, a circumstance which affords an easy test of its purity; for as this oil is often adulterated with olive and other light oils, all that is necessary is to pour the suspected oil into cold water, when the oil of cloves will sink, and the oil used as an adulterant will float on the surface. It appears, however, from recent researches that oil of cloves is composed of two distinct oils, one of which has a sp. gr. of 0.918, and is incapable of combining with bases; and the other possessing acid characters has a sp. gr. of 1.079. The indifferent oil is a hydrocarbon of the cloves, $C_{10}\,H_8$. The acid oil has the formula $C_{24}\,H_{15}\,O_5$. It has been named *Eugenic acid*. It is a transparent, colourless, oily liquid, with a strong odour of cloves, and a burning aromatic flavour. It forms a class of salts named *eugenates*, which have the taste and smell of the acid.

COACH, see Wheel Carriages.

COAL. There are several varieties of coal, all of which appear to have been formed by the action of certain chemical forces on wood or other vegetable matter; but these varieties may for the most part be arranged into two groups, the one containing no bitumen, and the other distinguished by the presence of that substance. In the first variety, or that without bitumen, is *anthracite*, also called *glance coal* and *stone coal*. It is compact and hard, with a high lustre, and is often iridescent. It takes a high polish, on which account it is often made into inkstands, boxes, and ornamental articles. Its specific gravity varies from 1.3 to 1.75. It contains from 80 to 90 per cent of carbon, with from 4 to 7 of water. In some varieties of anthracite bitumen is present, in which case it burns with a considerable flame. Indeed, anthracite passes gradually into bituminous coal, which varies greatly according to the amount of bitumen. The following are recognised varieties. *Caking* or *pitching coal* breaks into small pieces when heated, but on raising the heat they unite or *cake* into a solid mass. Its colour is velvet or greyish black. It burns with a lively yellow flame, but requires frequent stirring to prevent it from caking and so clogging the fire. *Cherry coal* resembles caking coal, but does not soften and cake: it is very brittle, and burns with a clear yellow flame. The *splint* or hard coal of the Glasgow coal beds is harder than cherry coal. *Cannel* or *candle coal* burns readily without melting, and has hence been used as *candles*, whence the name. It is of compact and even texture, little lustre, and breaks with a large conchoidal fracture. It is sometimes made into snuff-boxes, and similar articles. *Brown coal*, *wood coal*, and *lignite*, are imperfect varieties of coal, usually of a brownish black colour, and retaining the structure of the original wood, and burning with an empyreumatic odour. The substance termed *jet* resembles cannel coal, but is harder, of a deeper black colour, and higher lustre. It takes a brilliant polish, and is sometimes set in jewelry.

The following is a sketch of Liebig's views of the chemical processes which attend the formation of coal from wood. When wood is exposed to air and moisture it suffers decay or eremacausis: it moulders and becomes gradually converted into a dark brown or black powder, called *mould* or *humus*. The longer the process has been continued, the greater is the proportion of carbon in the residue. Thus oak wood is composed of $C_{36}\,H_{22}\,O_{22}$, and one specimen of oak humus was found to contain $C_{35}\,H_{20}\,O_{20}$, and another $C_{34}\,H_{18}\,O_{18}$; shewing that for every two equivalents of hydrogen oxidized by the air, one equivalent of carbonic acid had been separated. If the decay were to continue until all the hydrogen had been separated, wood, consisting of $C_{36}\,H_{22}\,O_{22}$, would leave only C_{25}; but this final result does not usually occur, because the excess of carbon retains the last portions of hydrogen with an increasing affinity as the amount of hydrogen diminishes.

When wood is decomposed by the action of water, air being absent, the process is more properly *mouldering*, for in eremacausis or decay oxygen is the active agent. In mouldering, the access of oxygen is very limited, and the results are different from those of decay. The elements of water together with some oxygen are taken up, and carbonic acid escapes. Thus when oak-wood was decomposed by lying under water, a white mouldered matter was formed containing $C_{33}H_{27}O_{24}$, and derived from oak-wood, $C_{36}H_{22}O_{22}$, by the addition of $5HO+O_3$ and the subtraction of $3CO_2$. Mouldered beech yielded $C_{33}H_{25}O_{24}$, which may be similarly accounted for. *Wood coal* or *brown coal* has been produced by a similar action. A pure specimen of wood-coal from Laubach contained $C_{33}H_{21}O_{16}$; that is, a greater proportion of carbon and hydrogen and a smaller proportion of oxygen than wood. If wood were to lose 3 atoms of carbonic acid and 1 atom of hydrogen, such a wood-coal would be the result:

For if from wood .... $= C_{36}\ H_{22}\ O_{22}$ we take
1 at. hydrogen, and 3 at. Carbonic acid $= C_3\ H_1\ O_6$
there will be left wood-coal .... $= C_{33}\ H_{21}\ O_{16}$.

In the formation of wood-coal the essential change seems to be the separation of carbonic acid from its elements, while a portion of hydrogen is removed by oxidation, owing to the limited access of air. The separation of carbonic acid seems still to go on even in the deepest beds of brown coal, and is probably the source of the acidulous springs found near such beds, and also of choke-damp in mines. When near the surface, the proportion of hydrogen in wood-coal is always less, owing to the action of the air, by the oxygen of which the hydrogen is removed.

Mineral coal appears to be produced by a long-continued decomposition of wood or of wood-coal, by which carbonic acid, water and carburetted hydrogen are separated. Splint coal and cannel coal are both $C_{24}H_{13}O$, which may be thus derived from wood:—

3 at. Carburetted hydrogen $C_3\ H_6$
3 at. Water .... $H_3\ O_3$
9 at. Carbonic acid .... $C_9\ \ O_{18}$

$$\left.\begin{matrix}\\ \\ \\ \end{matrix}\right\} \begin{matrix} C_{36}\ H_{22}\ O_{22} = \text{Wood} \\ C_{12}\ H_9\ O_{21} \\ \hline C_{24}\ H_{13}\ O = \left\{\begin{matrix}\text{Mineral}\\ \text{Coal.}\end{matrix}\right.\end{matrix}$$

Caking coal is $C_{20}H_9O$, or cannel coal *minus* olefiant gas, C_4H_4. This explains the occurrence of fire-damp in coal mines; whereas in mines of wood-coal carbonic acid or choke-damp alone occurs. The occurrence of fire-damp proves that changes are constantly occurring in the beds of coal. When the whole of the hydrogen is removed in the form of carburetted hydrogen, the residue must be ***anthracite***, which is nearly pure carbon.

By distilling coal with water, oily and resinous matters have been obtained. These oils and naphtha may be formed out of the elements of the carbonic acid and carburetted hydrogen separated from the wood during its conversion into coal; but if the wood had been originally of the pine tribe, the resin and oil of turpentine may have been originally present in it.[1]

Mr. Hutton has given decisive proof of the vegetable origin of coal, by submitting to microscopic examination an extensive series of slices taken from the several varieties of coal found at Newcastle and the contiguous district. He considers this coal to be of three kinds; the first, which is the greatest in quantity and the best in quality, is the rich *caking* coal, so generally esteemed; the second is *cannel* or *parrot* coal (*splint* coal of the miners); and the third, *slate* coal, consisting of the two former arranged in thin alternate layers with a slaty structure. In these varieties, taken indiscriminately, more or less of the vegetable texture could always be discovered, thereby affording the fullest evidence of the vegetable origin of coal. Each of these three kinds of coal, besides the fine distinct reticulation of the original vegetable texture, exhibits other cells which are filled with a light wine-yellow-coloured matter, apparently of a bituminous nature, and which is so volatile as to be entirely expelled by heat before any change is effected in the other constituents of the coal. The number and appearance of these cells vary with each variety of coal. In caking coal, the cells are comparatively few, and those which do exist are highly elongated. Their original form the author believes to have been circular, and he attributes their present figure to the distension of gas confined in a somewhat yielding material subject to perpendicular pressure. In the finest portions of this coal, where the crystalline structure, as indicated by the rhomboidal form of its fragments, is most developed, the cells are completely obliterated. In such parts the texture is uniform and compact: the crystalline arrangement indicates a more perfect union of the constituents, and a more entire destruction of the original texture of the plant. The slate coal contains two kinds of cells, both of which are filled with yellow bituminous matter. One kind is that already noticed in caking coal: while the other kind of cells constitutes groups of smaller cells of an elongated circular figure. In those varieties which go under the name of cannel, parrot, and splint coal, the crystalline structure, so conspicuous in fine caking coal, is wholly wanting, the first kind of cells is rarely seen, and the whole surface displays an almost uniform series of the second class of cells, filled with bituminous matter, and separated from each other by their fibrous divisions. Mr. Hutton considers it highly probable that these cells are derived from the reticular texture of the parent plant, rounded and confused by the enormous pressure to which the vegetable matter has been subject. The author states that though the crystalline and uncrystalline, or perfectly and imperfectly developed varieties of coal generally occur in distinct strata, yet it is easy to find specimens which in the compass of a single square inch contain both varieties. From this fact, as also from the exact similarity of position which they occupy in the mine, the differences in different varieties of coal are ascribed to original difference in the plants from which they are derived.[2]

Geological examinations of coal-fields have also afforded abundant evidence of the vegetable origin of coal, although the manner in which the *carboniferous*

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(1) Turner's "Chemistry," [illegible] Edited by Liebig and Gregory. London: 1847. "Chemistry in its application to Agriculture," &c. by Justus Liebig, &c. 4th Edition. London, 1847.

(2) "Proceedings of the Geological Society of London." No. 29. 1832—1833.

strata (as the *coal-measures*, or assemblage of rocks which include coal, are termed) have been deposited is by no means agreed upon. Some geologists suppose that the coal-measures were originally peat-bogs, and that the successive layers were occasioned by repeated subsidences of the land; others contend that the vegetable matter originated from *rafts*, like those of the Mississippi, which floated out to sea and there became engulfed; a third opinion is, that they were formed in vast inland seas or lakes, the successive beds of vegetable matter being supplied by periodical land-floods. All these causes may have been in operation in the formation of coal, but, however deposited, the coal is always accompanied by a thick bed of clay beneath every layer; and it is, moreover, a remarkable fact, that a common plant of the coal strata, named *Stigmaria*, invariably occurs, more or less abundantly, in this bed of underclay, although it is rarely to be met with in the coal or shale above.

If we trace the series of which a coal-field is composed, beginning with the lowermost stratum, we have: —1, the *underclay*, a tough, argillaceous substance, which changes upon drying into a grey, friable earth: it is sometimes black, from the presence of carbonaceous matter: it contains innumerable stems of Stigmaria, as already noticed; 2, then comes the coal, in which the external forms of plants, &c. are obliterated by the process of bituminization, although the internal structure remains; 3, the *roof*, or upper bed, which generally consists of slaty clay, abounding in leaves, trunks, stems, branches, and fruits,[1] and often containing layers of ironstone nodules, in which leaves, insects, crustacea, &c. are imbedded. Interstratified with the shale, finely-laminated clay, micaceous sand, grit and pebbles of limestone, granite, sandstone, and other rocks often occur. In fact, this bed appears to be an accumulation of drifted materials, mingled with the dense foliage and stems of a prostrate forest. "These phenomena," says Dr. Mantell, "may be explained by supposing the inundation of a thickly-wooded plain by an irruption of the sea, or of a vast inland lake, occasioned by the sudden removal of some barrier, or by a subsidence of the tract of country on which the forest grew. But when we find an accumulation of strata, in which triple deposits of this kind are repeated some thirty or forty times through a thickness of many thousand feet, a satisfactory solution of the problem is very difficult. Not only subsidence after subsidence must have taken place, but the first submergence have been followed by an elevation of the land—another soil fit for the growth of forest trees been produced—another generation of vegetables of precisely the same species and genera have sprung up, and arrived at maturity—and then another subsidence, and another accumulation of drift. And these oscillations in the relative level of the sea and land must have gone on uninterruptedly, through a long period of time, not in one district or country only, but all over the world, and during the same geological period."[2]

It will be understood from the preceding details that the series of rocks which constitute the coal-measures consists of beds of sandstone, shale, clay, and coal, lying one above another in repeated alternations to a great depth. The strata of coal, technically called *seams*, are very thin compared with the other associated beds. Although they extend under large tracts of country, they are often only a few inches thick, seldom more than 6 or 8 feet, except one seam in Staffordshire, which is 30 feet thick, but this must be regarded as a collection of minor seams nearly in contact. Under this series is the mountain limestone, forming various calcareous strata of variable thickness, sometimes exceeding 900 feet. This limestone rests on a bed of old red sandstone, varying in thickness from 200 to 2,000 feet. The term *coal formation* sometimes includes these two great series of strata, although, in general, the coal-measures lie above them, the lowest coal seam commonly resting on the mountain limestone.

The various deposits which form the coal-measures do not occur in regular horizontal unbroken planes, as might be supposed. There is no doubt that when first deposited they were in this condition, but this horizontal position has at various times been disturbed by some upheaving force from below, whereby the coal-measures have, in many districts, been made to assume the shape of a huge trough or *basin*, rising on all sides from a central point, the sides of the basin being composed of sandstone or limestone, and the middle filled up by strata superior to the coal-measures, viz. magnesian limestone, and new red sandstone. This will be better understood by referring to the diagram, Fig. 571, which represents a section across a coal-field, such as would result from making a deep perpendicular cut in the ground, and removing all the strata on one side; we should then see a wall exposed like a vertical cliff on the sea-shore.

Now it follows from the arrangement of these coal-basins, that the edge or boundary line of each stratum must appear at the surface somewhat like the concentric layers of an onion cut in two. This "coming to the day," or appearance of the coal at the surface of the ground, is called the *basset* or *outcrop*, and serves to determine the outer form or side of the basin. Coal-basins are generally elliptical in shape, but they are sometimes nearly circular and very often eccentric, being much greater in length than in breadth. Thus the great South Welsh coal-field, which comprises an area of upwards of 900 square miles, is in the form of a long-necked flask. In many cases one side of the basin upon the narrow diameter inclines more, or has a much greater *dip* than the other, whereby the trough or lower part of the basin is thrown much nearer to one side than the other. Hence it is evident that in a perfect basin all the strata regularly crop out, and meet the surface in every point of its boundary. Few coal-fields are, however, thus circumscribed, by the outcropping of older strata. The two great fields of Northumberland and South Wales are bounded (the one on the east and the other on the south) by the sea, so that they are, strictly, only half basins. The Leicester and Warwickshire field has none of the characters of a basin, being surrounded on all sides by overlying strata, under which the coal-measures dip lower and lower, till they become too deep to be profitably worked: thus they have no outcrop, and their extent is unknown; but they probably extend under the surrounding new red sandstone into the Lancashire and other fields. (See Fig. 571, B.)

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[1] Dr. Buckland, in his "Bridgewater Treatise," thus refers to the coal deposits of Bohemia:—"The most elaborate imitation of living foliage upon the painted ceilings of Italian palaces, bears no comparison with the beauteous proportions of extinct vegetable forms with which the galleries of these instructive coal mines are overhung. The roof is covered, as with a canopy of gorgeous tapestry, enriched with festoons of most graceful foliage, flung in wild irregular profusion over every portion of its surface. The effect is heightened by the contrast of the coal-black colour of these vegetables with the light ground-work of the rock to which they are attached."

[2] "Medals of Creation; or, First Lessons in Geology, &c.," by Dr. Mantell. 2 Vols. London. 1844.

The internal upheaving force, whatever it may have been, which converted the horizontal strata into basin-shaped arrangements, probably produced at the same time certain fissures or fractures often nearly vertical, and stretching through the whole mass. (See Fig. 572.) These rents are of great importance to the miner, and may be beneficial to him, or not, according to circumstances. They are called *dykes*, because they divide the seams or bands of coal into *fields*, and are *up-throw* or *down-throw* dykes, according as the edge of the strata appears to an observer to be higher or lower in regard to his own position. They are also called *shifts*, as the miners consider that they have *shifted* the strata on their sides; but the common term is *faults* or *troubles*, from their *troubling* or putting to *fault* the pitmen.

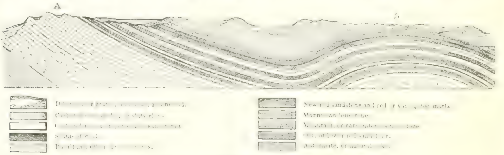
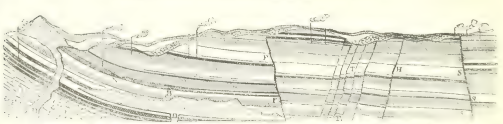

A
B.
Diluvium, or gravel, sand, clay, and mud.
Carboniferous shale, or slate clay.
Carboniferous grit, or coarse sandstones
Strata of coal.
Basalt, and other igneous rocks.
New red sandstone and red or variegated marls
Magnesian limestone
Mountain, or carboniferous limestone
Old, or lower red sandstone.
Anthracite, or natural coke.

Fig. 571. SECTION OF THE GENERAL FEATURES OF COAL FIELDS.



D D, Whin Dykes; F F, S S, Faults or Slip Dykes; T T, Troubles; H, Hitch or Slip; *b* and B B', Bands; N, Nip or Baulk.

Fig. 572. ENLARGED SECTION OF THE ACCIDENTAL FEATURES OF COAL FIELDS.

Some of these dislocations of strata are so considerable as to obtain a place in geological maps. In the Northumberland and Durham coal-field, the most remarkable is called the *Main* or *Great Dyke*, or *Ninety-Fathom Dyke*, in which the beds on the north side are *ninety fathoms* lower than those on the south side of this dyke. The width is variable, in some places not great, but in Montague Colliery it is 22 yards wide, and is filled with hard and soft sandstone. Two other dykes branch off from the south side of this dyke, one to the south-east, which is 20 yards broad, and the other to the south-west, which, from its breadth, is called the *Seventy-Yard Dyke*. It is filled with sandstone, and intersects the upper seam of coal, which, however, does not appear to be thrown out of its level by the interruption. A slip dyke of less thickness than the workable seams, and not disturbing their continuity, is called a *hitch*, as at H, Fig. 572.

Other dykes, called *whin-dykes*, contain basalt, toadstone, and other rocks of igneous origin. Such dykes may, or may not be *slip* dykes, or such as cause a shifting of level in the adjacent beds. Thus those at D D, Fig. 572, are not accompanied by any slip. In approaching within a few yards of these once molten streams, the operation of fire is evident in the conversion of loose grits into compact quartz, and of clay or shale into slate and porcelain jasper, while the coal-seams are diminished in thickness and completely charred, or converted into blind-coal, anthracite cinders, sooty ashes, or in some cases coke, as perfect as that obtained from a coke oven. When basaltic or other igneous dykes reach the surface, or what was the surface at the time of their protrusion, their matter is either heaped up so as to form a hill, as in D, to the left of Fig. 572, or spread out into undulating masses, as occurs with the other dyke, D, in the same figure, or sometimes into extensive strata, destroying a vast extent of coal, or converting it into anthracite, as in the Ayrshire field.

It will readily be supposed that dykes are a frequent source of difficulty and expense, by throwing the seams out of their levels and filling the mines with water and inflammable gas, whereby many fatal accidents arise. On the other hand, dykes and faults have their advantages; for when they are filled, as is often the case, with stiff clay, numerous springs of water are dammed up, and brought to the surface, instead of being poured into the mine. By means, also, of these dykes, valuable beds of coal are preserved within the field which would otherwise have cropped out and been lost. Thus the general depression between the faults F F and T T brings in two thick seams, which would not otherwise occur in this part of the field, as they belong to a higher level. Several valuable beds of coal near the main dyke would not have been available but for the general depression of the beds occasioned by that chasm.

Among the other accidental features of coal-fields may be mentioned *bands*, or thin strata of grit or shale in the heart of a coal-seam, and from a scarcely perceptible origin, as B, Fig. 572, gradually thickening, until, at a distance of perhaps many miles, they entirely usurp the place of the coal, or reduce a thick and valuable seam to a thin and useless one. A sudden local thinning of the seam by an excrescence from the roof or floor, as at N, is called a nip: this, however, is of rare occurrence.

Such are the general features of coal-measures. Mineral coal is widely distributed over the world. It constitutes the most important of the mineral treasures of Great Britain. It is found in France, Spain, Portugal, Belgium, Germany, Austria, Sweden, Poland, and Russia. It is abundant in some parts of India, China, Madagascar, Van Diemen's Land, Borneo and the other East India Islands, New Holland, and at Conception in Chili. But the most extensive known deposits are in the United States of America, where there are four great areas occupied by this formation. One of them commences on the north in Pennsylvania and south-eastern Ohio, and sweeping south over western Virginia and eastern Kentucky and Tennessee to the west of the Apalachians, it continues to Alabama, near Tuscaloosa. It has been estimated to cover 63,000 square miles. A second coal area (the Illinois) lies adjoining the Mississippi, and covers the larger part of Illinois, the western part of Indiana, and a small north-west part of Kentucky: it is but little smaller than the preceding. A third occupies a portion of Missouri, west of the Mississippi. A fourth covers the central portion of Michigan. There is, also, a small coal region in Rhode Island. Beyond the limits of the United States, on the north-east, commences a sixth coal area, that of Nova Scotia and New Brunswick, which covers 10,000 square miles. At Cape Breton is still another coal-field.[1]

The coal-measures of Great Britain are variously dispersed in the midland, northern, and western portions of South Britain, and in a broad belt of country which traverses the centre of Scotland, from the shores of Ayrshire to those of the Frith of Forth. There are, also, some coal tracts of far inferior importance in Ireland.

The Table on the next page will give the reader a tolerably complete idea of the value of the coal of the British Islands. Commencing with the first in the list, the coal-pits on the eastern side of the island occupy a large portion of the counties of Durham and Northumberland, and are the most important of all pits which are wrought for the sale of coal. This great tract supplies not only the whole of those counties, the North Riding of Yorkshire, and the contiguous Scottish counties; but the whole of the eastern and southern coasts of England, as far as Cornwall, including the metropolis itself, and the great south-eastern region, into which the sales of the inland coal districts do not penetrate, on account of the greater cost of land carriage, and the want of canals. There is also an extensive export to foreign parts. This important region is sometimes divided into two districts, that of *South Durham*, south of the river Wear, and that of *North Durham* and *Northumberland*, comprising the rest of the field. 2. In the Cumberland coal-field, the pits are wrought only for sale, for the purpose of supplying the counties of Cumberland and Westmoreland, and for shipment chiefly at Whitehaven to Ireland, and the opposite shores of Scotland. In the West Riding of Yorkshire, the coal-pits supply extensive iron-works, and they also furnish fuel to a great part of Yorkshire, except the coast, and make some shipments down the Humber for London. 3. The coal-fields of Lancashire extend southward into the eastern part of Cheshire, and are worked to an enormous extent for the supply of the manufactures congregated in their neighbourhood; but there is no manufacture of iron from native ores in this district, or only to a very small extent. On the eastern border of *North Wales*, in Denbigh and Flint, bordering upon Cheshire, there are iron-works, and the coal-field supplies with fuel nearly the whole of North Wales, and a large portion of Cheshire and Shropshire. In North Staffordshire, besides the coal-field of the potteries, in which there are extensive iron-works at Kidscrew, there is a smaller tract contiguous to the town of Cheadle. 4. In the vale of the Trent, between Nottingham and Derby, commences the great coal-field of Derbyshire and Yorkshire, which extends hence northward, and of which the southern or Derbyshire portion occupies the eastern side of that county, and extends at one extremity into Nottinghamshire. Besides supplying with fuel a vast surrounding region, especially to the east and south in the counties of Leicester, Nottingham, and Lincoln, it has a considerable home consumption in iron-works. 5. 6. The most important coal-field in the midland counties is that of *South Staffordshire*, which, lying to the west and north of Birmingham, is remarkable for the extent to which its vast beds are worked, as well for the purpose of smelting the iron ores, which are raised from strata interspersed among the coal strata, as for the consumption of the neighbouring populous towns which are the seat of the metal manufactures, and for an extensive

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[1] "Dana, Manual of Mineralogy." Newhaven 1848. The reader who desires to study the subject of coal with reference to its geographical, geological, and commercial distribution, &c. is referred to the "Statistics of Coal," by R. C. Taylor, F.G.S. &c. London and Philadelphia 1848.

"land sale," as the supply of the surrounding country with fuel is designated, the country southward, where canals extend as far as the Thames, being in great part supplied from this region. The *Shropshire* district of Coalbrookdale, lying midway between Wolverhampton and Shrewsbury, though much smaller in extent, is also the seat of great iron-works, and is the source of a supply of fuel for a great part of the vale of the Severn, and the country to the west of it, to the borders of Wales. The *Warwickshire* coal-field occupies a large tract on the north-eastern verge of that county, from Coventry to Tamworth; and the *Leicestershire* coal-field surrounds the town of Ashby-de-la-Zouch. The coal of the latter is far more extensively wrought than that of the Warwickshire field; but both being without iron furnaces, their produce is required only for the land sale, which extends southward through Buckinghamshire to the Thames. 8. The *Forest of Dean* is a remarkable detached coal-field in Gloucestershire, between the confluent rivers Wye and Severn, in which pits are wrought for the manufacture of excellent iron ores, and for the supply not only of the contiguous parts of Herefordshire and Gloucestershire, but also for a considerable land sale eastward towards Oxford. South Gloucestershire is in great

TABLE OF THE PRINCIPAL COAL-FIELDS OF THE BRITISH ISLANDS.

	Estimated workable area in acres.	Number of workable seams.	Estimated total thickness of workable coal in feet.	Thickest bed in feet.	Thickness of coal-bearing measures in feet.
1. *Northumberland and Durham district.*					
Newcastle coal-field	500,000	18	80	7	
2. *Cumberland and Westmoreland, and West Riding of Yorkshire.*					
Whitehaven and Akerton	80,000	7		8	2,000
Appleby (3 basins)	17,000				
Sebergham (Cumberland)	?	1	3	3	
Kirkby Lonsdale	2,500	4	17	9	
3. *Lancashire, Flintshire, and North Staffordshire.*					
Lancashire coal-field	380,000	75	150	10	6,000
Flintshire	120,000	5	30	9	200
Pottery, North Staffordshire	[illegible]	24	38	10	
Cheadle, ditto	10,000				
4. *Yorkshire, Nottinghamshire, Derbyshire.*					
Great Yorkshire coal-field	650,000	12	32	10	
Darley Moor, Derbyshire Shirley Moor, ditto	1,500				
5. *Shropshire and Worcestershire.*					
Colebrook Dale, Shropshire	21,000	17	40		
Shrewsbury, ditto	16,000	3			
Brown Clee-hill, ditto	1,300	3			
Titterstone Clee-hill, ditto	5,000				
Lickey-hill, Worcestershire	[illegible]	?	?	?	
Bewdley ditto	45,000	?			
6. *South Staffordshire.*					
Dudley and Wolverhampton	65,000	11	67	40	1,000
7. *Warwickshire and Leicestershire.*					
Nuneaton	40,000	9	30	15	
Ashby-de-la-Zouch	40,000	5	33	21	
8. *Somersetshire and Gloucestershire.*					
Bristol	130,000	50	90		
Forest of Dean	36,000	17	37		
Newent, Gloucestershire	1,500	4	15	7	
9. *South-Welsh coal-field*	600,000	30	100	9	12,000
10. *Scottish coal-fields.*					
Clyde Valley Lanarkshire South of Scotland, several small areas	1,000,000	24	200?	13	6,000
Mid-Lothian	?	24	94		4,400
East-Lothian	?	60	180	13	6,000
Kilmarnock Ayrshire	?	3	40	30	
Fifeshire	?	?	?	21	
Dumfries coal region	45,000	10	55	6	
11. *Irish coal-fields.*					
Ulster	500,000	9	40?	6	
Connaught	200,000				
Leinster (Kilkenny)	150,000	8	23		
Munster (several)	1,000,000				

part occupied by a coal field, which extends northward from Bristol, and supplies that city and the contiguous country with fuel. There are also valuable basins in *North Somersetshire*, the principal being those to the south-west of Bath, which supply the contiguous country, and have also an extensive sale eastward in Wiltshire and Berkshire. 9. The most extensive coal-basin of the west is that of *South Wales*, which, commencing in Monmouthshire, occupies a considerable portion of the counties of Glamorgan, Carmarthen, and Pembroke. The internal consumption of its coal in the manufacture of its native ores of iron, and of those of copper and tin brought from Cornwall and other parts, is enormous, and, besides supplying with fuel the whole of South Wales and its borders, Cornwall, and a considerable part of Somersetshire, it exports large quantities of stone-coal even to London. 10. The coal districts of the *East of Scotland* encircle the Frith of Forth in tracts of very irregular form, occupying large portions of the counties of East Lothian, Mid-Lothian, and West Lothian, of Stirlingshire, and part of Dumbartonshire, of Clackmannanshire, and Perthshire, and of Fifeshire, in the districts of Dunfermline, Kirkadly, Cupar, and St. Andrews. The coal of the whole of those districts is extensively wrought, chiefly for land sale to Edinburgh and the surrounding counties, and partly for shipment coastwise and for the celebrated iron-works of the Carron Company in Stirlingshire.

Lanarkshire, Ayrshire and Renfrewshire comprise nearly the whole of the irregularly scattered coal-fields of the *West of Scotland*, and their mines have been chiefly wrought, like those of Lancashire, for the supply of the great manufacturing population, of which Glasgow is the centre. The district of Airdrie, to the east and south-east of Glasgow, is also rising into importance in the manufacture of iron, from the excellent ores there found, so that the working of its coal has greatly increased.

There are also in Great Britain other very small coal tracts not sufficiently important to call for special notice.

11. The coal-fields of Ireland are comparatively unimportant. The principal are those of Castlecomer in Kilkenny, and the Queen's County, where pits are worked; pits are also worked near Killenaule, in the county of Tipperary; Dromagh and Dysart, in the county of Cork; Drumglass and Coal Island, in the county of Tyrone, which, with the Arigua coal-pits at the northern extremity of Roscommon, supplying some contiguous iron-works, complete the list of the Irish coal-mines in actual operation.

In addition to the enormous demands made on our national stock of coal by our own domestic consumption and our various manufactures, there is also a very large export trade in coal, which has greatly increased since the repeal of the duty, in 1845. In 1857, coal was exported of the declared value of 3,210,661*l.* This is doubtless an advantage for ships that might otherwise have had to go out in ballast, for they can now take with them a profitable cargo. Whether this lavish expenditure of our national wealth is reprehensible or not, is a question that has been very much discussed of late years, and has even been made the subject of parliamentary inquiry. The general opinion is that our stores of coal are all but inexhaustible. This opinion, however, as Mr. Sopwith justly remarks, "rests wholly on assumed data, and not upon accurate and detailed statistical accounts, such as alone could warrant a confident opinion. This question will ere long become a subject of serious concern, unless some measures are taken to found our calculations on a solid basis. It is an easy matter to assume that a considerable thickness of available coal extends over hundreds of square miles; but the different opinions formed by men of the highest respectability and talent, strongly prove how meagre and unsatisfactory are the only data on which their estimates are founded. It is not, however, the mere quantity of coal that is to be considered. Especial regard must be had to its quality, depth, thickness, extent, and position. Many of the inferior seams can only be worked in conjunction with those which, by their superior quality, repay the expense of working them at depths varying from 300 to 600 yards; and it may readily be conceived that inferior coal only could not be profitably raised from pits equal in depth to three or four times the height of St. Paul's Cathedral, unless the price of such inferior coal were raised to more than the present price of the best coal. . . . It is not the exhaustion of mines, but the period at which they can be profitably worked, that merits earnest and immediate attention."

The Table on the next page, from the valuable report of Sir H. De la Beche and Dr. L. Playfair (Mem. Geol. Survey, vol. ii.), contains the elementary analyses and economic value of British coals.

In proceeding to notice the methods of obtaining the coal, and the general economy of a mine, we will first refer to the collieries of Northumberland and Durham, as exhibiting the most perfect arrangements that have yet been made in this department of mining.

The first operation in coal mining is the sinking of a shaft, the site for which is generally determined by the previous operation of boring. The shaft is vertical, and is made to pass through the various strata containing the coal, and through as many of the beds of coal as may be worth working. The shaft is either cylindrical or elliptical in form, and from 10 to 15 feet in diameter. To prevent the loose strata from falling or being washed in, the upper portion of the shaft is bricked or walled, and where the ground is weak, this casing is continued down to the solid rock. It seldom happens that any great depth can be reached without liberating springs of water, which sometimes pour into the workings in such cataracts, that to continue the excavation seems perfectly hopeless. The water is, however, gradually excluded from the shaft by a skilful system of casing or *tubbing;* which consists in lining the shaft with three-inch boards, fastened to a circular wooden framework called a ***crib***, attached to the side at certain distances. Metal cribbing is now generally preferred, and some recent shafts have been completely lined with a strong casing of cast-iron to the depth of 40 fathoms (240 feet). The work, however, could scarcely be proceeded with for a single hour but for the assistance of the steam-engine, which is made to work night and day in drawing the water from the shaft. The sinking of the shaft is continued until the first workable seam of coal is reached, and the depth in the northern coal-field is rarely less than 25 fathoms (150 feet), and is usually much more, some shafts being 300 fathoms (1,800 feet); and an expense of upwards of 50,000*l.* has often been incurred before the seam intended to be worked is reached.

		Specific gravity.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Coke per cent.	Evaporative power	
Welsh Coals.	1	1.375	91.44	3.46	0.21	0.79	2.58	1.52	92.9	9.46	Anthracite.
	2	1.275	89.78	5.15	2.16	1.02	0.39	1.50	77.5	10.21	Ebbw Vale.
	3	1.304	88.66	4.63	1.43	0.33	1.03	3.96	88.10	9.94	Binea Coal.
	4	1.326	88.26	4.66	1.45	1.77	0.60	3.26	84.3	10.14	Duffryn.
	5	1.358	85.52	3.72	a trace	0.12	4.55	6.09	85.0	6.36	Pentrefelin.
	6	1.30	84.87	3.84	0.41	0.45	7.19	3.24	85.5	9.35	Graigola.
	7	1.32	80.70	5.66	1.35	2.39	4.38	5.52	64.8	7.47	Ponty Pool.
	8	1.34	75.15	4.93	1.07	2.85	5.04	10.96	62.5	8.84	¾ Rock Vein.
	9	1.29	73.81	5.11	1.17	2.31	8.29	8.92	56.0	8.0	Coleshill.
Scotch.	10	1.277	71.55	5.11	0.10	0.33	15.51	4.37	49.8	7.08	Dalkeith, Jewel Seam.
	11	1.316	76.91	5.20	a trace	0.38	4.37	3.10	53.5	7.71	Do. Coronation Seam.
	12	1.20	76.09	5.22	1.41	1.53	5.05	10.70	58.45	8.46	Wallsend, Elgin.
	13	1.25	79.58	[illegible]	1.13	1.46	8.33	4.00	52.03	7.56	Fordel Splint.
	14	1.29	79.85	5.28	1.35	1.42	8.58	3.52	56.6	7.40	Grangemouth.
English.	15	1.25	81.70	6.17	1.84	2.85	4.37	3.07	59.2	7.3	Broomhill.
	16	1.283	73.52	5.69	2.04	2.27	6.48	10.00	57.8	8.52	Parkend, Sydney, Forest of Dean.
Irish	17	1.59	80.03	2.30	0.23	6.76	in ash	10.80	90.1	9.85	Slievardagh.

When, however, this desirable object has been attained, the sinking of the shaft is discontinued, and a broad straight passage, called a *bord* or *mother-gate*,[1] is driven from it into the seam of coal in opposite directions. This bord is 12 or 14 feet broad, and of the whole height of the seam, so as to expose the rock above, which is now called the *roof*, and also the stratum below, which forms the *thill* or floor. It is also necessary to drive a passage, called the *drip-head*, *dip-head*, or *main level*, for collecting the water of the mine. This passage is not usually straight, but the object is to preserve throughout its length a constant level, so that the water may collect like a gutter along one side of its floor. This gallery forms the limit of the colliery in the direction of the dip, for it bounds the area drained or *won* by that shaft. From this level gallery numerous other galleries are driven towards the rise of the strata, till they reach either the outcrop of the seam, or the dip-head gallery of an adjoining colliery, which is called the *rise* colliery. The direction of the bords is arranged so as to follow the natural cleavage of the coal, which forms their sides, and, consequently, is not always at right angles with the dip-head. When a bord has been excavated some distance, narrow passages, called *headways*, are driven from it, at regular intervals, on both sides, and exactly at right angles, if the natural cleavage of the coal be cubical, as it generally is; and when these have been driven 8 or 10 yards, they are made to communicate with other bords, which are opened parallel to the first, and on each side of it. In this way, the bed of coal is entirely laid open, and intersected by broad parallel passages, about 8 yards apart, communicating with each other by narrower passages or headways, which cross them at right angles, and also traverse the whole extent of the mine, breaking up the seam into immense squares or rectangular pillars, which are left standing between the two. In this state, a coal mine has been aptly compared to a regularly built town, the bords being the principal streets, the headways the narrower streets which cross them, while the pillars of coal form the masses or blocks of buildings When the two cleavage planes of the coal are not at right angles, all the blocks are rhomboidal, and much labour is saved by following the natural cleavages, which are usually parallel throughout a vast extent of country, and are even independent of the curvatures of the strata.

As the pillars of coal which are left to support the roof form frequently as much as three-fourths, and never less than one-third of the whole seam, many methods have been contrived for removing them without danger. The best method of working is that called *panel-work*, by which the mine is divided into districts or panels, separated from each other by walls of coal forty or fifty yards thick. The coal is extracted from each in succession, beginning usually with the one most distant from the shaft. Large pillars of coal are first left between the bords to support the roof; the pillars themselves are then removed, the roof being supported in the mean time by wooden props, and the place where these props occupy the situation of a pillar is called a *jud*. In time, the jud is removed, and then the unsupported roof of the mine falls in. The heap of ruins thus occasioned by the successive drawing of contiguous juds, is called a *goaf*. Corresponding with this heap of rocky frag-

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(1) That is, a "principal road," the Saxon meaning of *gate* being *road* or *way*.

ents, and produced by it, is a cavity in the mine, like an inverted basin, including a thin belt of air, which surrounds and partly permeates the goaf. This has been the source of dangerous accidents, as will be noticed hereafter.

Fig. 573, is the plan of one story of such a mine, in which the panels, *a a a a*, are not entirely laid open by galleries; *b b* are laid open, but no pillars as yet removed; in *c c*, the pillars are being extracted and the roof is falling in, its ruins forming a *goaf;* the panel *d*, is entirely worked out and abandoned.

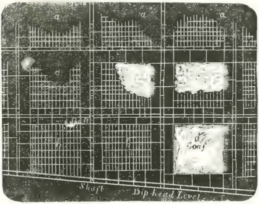

Fig. 573. PLAN OF ONE STORY OF A MINE.

When the prospects of the mine appear to be favourable, another shaft is, in some cases, sunk at a short distance (perhaps from 12 to 20 yards) from the first, and when a communication has been established between them, one is made the *downcast* and the other *upcast;* that is, the air necessary for the ventilation of the mine is made to descend the downcast shaft, and a corresponding stream of air to ascend the upcast shaft. The air is set in motion by means of a large fire, kept constantly burning in some part of the upcast shaft. A portion of the air in contact with the fire in this shaft undergoes the ordinary chemical change which takes place in atmospheric air in the process of combustion, and is decomposed: the nitrogen is separated, and the oxygen, uniting with the carbon of the fuel, forms carbonic acid gas. Both these gases, as well as the portion of atmospheric air which remains undecomposed, being heated, are expanded, and occupy a proportionally larger space than the same weight of common atmospheric air, and are hence borne upwards in a strong ascending current. Now if a free communication be established between the two shafts, an equal current must at the same time descend the second or downcast shaft to fill up the partial vacuum which has been made in the first. In this way a power is generated capable of forcing a current of fresh air far beyond the distance to which any mine extends. The great generator of this power is the fire, and this power will act with a force and steadiness proportionate to the degree of heat steadily maintained at the bottom of the upcast shaft.

When two shafts have been sunk, and a horizontal road or communication is made between them, the next operation is to carry forward a mainway from the foot of each shaft, and then to make a road from the extremity of one mainway to the extremity of the other. If a door be now placed in the road which leads directly from the foot of the one shaft to the foot of the other, the air cannot then pass that way, but must go round along the one mainway across to the other, and thus to the foot of the shaft in which there is the fire, up which shaft the current must ascend. To whatever distance we suppose the mainways, the sideways, and all the other works of the mine to be carried, communications may thus be made between them, and by means of doors properly placed the circulation of the air may be conducted and guided through them to any extent, and in any direction that may be desired. Fig. 574, will show the principle of these ventilating arrangements. The arrows indicate the course of the air through the underground passages, from the downcast to the upcast shaft; and the lines drawn from one pillar to another show the trap-doors, or partitions, which prevent the current of air diverging to the upcast shaft before it has swept the more distant workings.

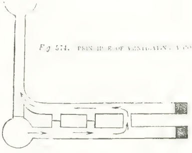

Fig. 574. PRINCIPLE OF VENTILATING A COAL-PIT.

The supplies of fresh air passing into a mine must, of course, vary considerably. In the Wallsend colliery they vary from 2,000 to 3,000, and occasionally 3,800 cubic feet per minute. In some of the large workings, the air has to traverse many miles of gallery before it reaches the upcast shaft, and is frequently twelve hours in doing so, moving at the ordinary rate of 2 or $2\frac{1}{2}$ feet per second. Many coal mines are worked without this second shaft, its place being supplied by dividing the single shaft into two distinct portions, by means of an air-tight partition, called a *brattice*, one division being downcast, and the other upcast. The larger shafts (those 15 feet in diameter) are sometimes divided into three parts, one of which is used for raising the coal to the surface, another for working the pumps for the drainage of the mine, and a third for ventilation, for bringing up the air that has passed through the workings.

The arrangements thus far explained for sinking a shaft and driving galleries into one seam of coal being conducted with success, the sinking of the shaft is continued to a second or third seam. Small underground pits, called *staples*, are sunk at intervals from the workings on the upper seam to those on the seam below, for the purpose of promoting ventilation. In this way an extensive colliery is formed; but the regularity and uniformity of the workings are liable to be greatly disturbed by faults and local accidents. For example, if the roof be of hard sandstone and the floor of soft clay, the downward pressure will tend to force up and displace the floor; this is called a *creep*. If, on the contrary, the roof be soft, it will sink in and form what is called a *crush;* and if both roof and floor are moderately hard and tough they will gradually meet midway. The gradual progress of a creep is shown in Fig. 575, by which the passages become choked up, and the pillars of coal are cracked and rendered useless. By the method of working in panels, however, a creep in one panel is prevented, by the thick surrounding walls, from spreading into the adjoining panels.

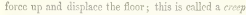
Fig. 575. PROGRESS OF A CREEP.

The coal is excavated by a set of men named *hewers*. They commence by cutting a narrow fissure in the lower portion of the coal, next the thill or floor; they then define the size of the mass intended to be brought away, by cutting deep vertical grooves on each side of the bottom fissure: the mass is then broken down by driving in wedges, or by the force of gunpowder, the latter method being usually adopted in the deep northern mines. A hole about a yard deep is drilled near the roof, and the cartridges of gunpowder, called *shot*, are inserted. Sometimes two or three shot are inserted; the holes are filled up with coal-dust, and the fuse is fired. By this means from 60 to 80 or 100 tons of coal may be brought down at once. The coal is put into baskets, called *corves*, and drawn along the tram-road by lads called *putters* as far as the principal galleries, or headways, where it is received into wagons, called *rolleys*, several of which, being fastened together, are drawn by a horse to the bottom of the shaft, and thence raised by means of the steam-engine to the surface (see Fig. 593). The small coal is separated from the larger by being passed over gratings or screens, usually composed of bars of iron half an inch apart, mounted in a frame-work with a convenient slope, so as to allow the coals to slide down easily into the wagons below. The small coal which passes through the screen is either delivered in wagons for immediate sale, or is collected into heaps, or is hoisted up and passed through screens in which the bars are set closer together, and is thus sorted into *rough*, *small*, and *dust*. The small coal, which was formerly burnt to waste at the mouth of the pit at the rate of about a million tons per annum, is now profitably employed in making coke for locomotive engines, iron works, brewers, &c., and for consumption abroad. It is also a curious sign of the times that in some collieries machinery has been erected for crushing large coal into small, in order to meet the increasing demand for coke.

"Pit-coal is produced by a severity of labour, and risk of personal safety to the miner, which the workman of no other occupation is exposed to. The pitman descends 200, 300, and sometimes more than 500 yards into the bowels of the earth, and there traverses subterranean passages, frequently of two or three miles in extent, to his work; where, by the glimmering of a small candle, or more imperfect lamp, in a space seldom six feet high, and oftener three or four, he labours in a stooping posture, sometimes lying on his side for eight or ten hours together, in an impure atmosphere, to extract the mineral, which above ground is diffusing light, heat, riches, and enjoyment. In such a situation often, without a moment's warning, he is overtaken by destruction. The gases generated in such abundance in the mine, from some accident suddenly explode and fill the pit with death. In an instant, and in the most fearful manner, he is scorched and shrivelled to a blackened mass, or is literally shattered to pieces against the rugged sides of the mine; or, if out of the range of this terrible piece of ordnance, in a few seconds the *after-damp* spreads itself in every direction, and poisons beyond recovery all that it may reach. Humanity has too frequently to deplore these fearful accidents."[1]

The accidents arising from the falling in of the roof, and the bursting in of water, are not peculiar to coal mines. The great and terrible source of danger which distinguishes coal-mines, and especially those of the great northern coal-field, is the escape of large quantities of *fire-damp*, or carburetted hydrogen gas, which, mingling with the air of the mine in certain proportions, forms a mixture which explodes on contact with flame. This gas is very much lighter than common air, mingles readily with it, and when poured out into the workings, moves along with the ventilating current in the direction of the upcast shaft. The quantity of gas thus poured out is very considerable, but subject to great variation, some seams being more *fiery*, or full of gas, than others; and, in working these fiery seams, it is not uncommon for a jet of inflammable gas to issue from every hole made for the gunpowder used in blasting. But, in addition to this constant supply, there is danger of sudden discharges from cavities in the coal, laid open by the hewer's pick-axe. The gas issues from these cavities with considerable noise, and forms what is termed a *blower*. These blowers are sometimes so constant in their action, that the gas is collected and conveyed by a tube into the upcast shaft, continuing for months or years to pour out hundreds or thousands of hogsheads of fire-damp per minute. When thus provided for, the blowers are not, necessarily, a source of danger; but when one of the reservoirs containing the pent-up gas of centuries, and consequently under an enormous pressure, is suddenly broken open, the gas is set free in torrents, and, mingling with the air of the mine, forms an explosive mixture which the first spark or naked flame may ignite, and thus cause a fearful destruction both of life and property. Nor is the explosion itself always the thing to be dreaded most; for the ignition of the fire-damp kindles the coal-dust, which always exists in great quantities in

(1) Report of the South Shields Committee.

the passages, and, in a moment, causes the mine to glow like a furnace. This conflagration is necessarily succeeded by vast volumes of carbonic acid, or *choke-damp*, as it is emphatically called, from its suffocating character, and this destroys those whom the explosion had spared.

It was to guard against the explosion of fire-damp, that Sir Humphry Davy invented his safety lamp, Fig. 576, a beautiful and simple contrivance, consisting merely of a common oil lamp, the flame of which is completely enclosed within a cylinder of wire gauze, which, as already explained in our article CANDLE, will not admit of the passage of flame; so that although the lamp be introduced into an explosive mixture, the flame will not pass through the gauze to ignite it. Of course, the efficacy of the lamp depends on the soundness of the wire gauze, for if this be broken and injured, the flame is not protected; or if the lamp be moved swiftly through an explosive atmosphere, the flame may be blown against, and even through the meshes of the gauze, and, in either case, might lead to an explosion. When the lamp burns in an atmosphere highly charged with fire-damp, the gas gets within the meshes, and burns with a blue flame, which heats the wire gauze to redness. Even this state of the lamp will not produce an explosion, but of course it was never intended that the workman should go on working with the lamp in this state. The blue flame within the lamp ought always to be a caution to him to retire, until the mine be rendered safe by ventilation. The Davy lamp has been in some respects improved upon by Dr. Clanny, whose safety lamp, Fig. 577, differs but little in form from the Davy. The gauze is of the fineness of 1,296 meshes to the square inch. The air for supporting combustion passes through the meshes down upon the flame, which is surrounded by a thick well annealed glass cylinder. By this means, the atmospheric air when mixed with fire-damp at the exploding point, becomes greatly expanded in volume, and passes off in safety. It gives a better light than the Davy, and burns for a longer time. When the flame is extinguished by fire-damp, the blue flame in the whole cylinder disappears quietly, thus indicating to the miner the nature and extent of fire-damp contained at the moment in the atmosphere of the mine. The flame of the lamp being surrounded by a glass cylinder, prevents any blown or unmixed fire-damp, or strong currents of fire-damp, however explosive or dangerous, from coming in direct contact with the flame, nor can the pitman unscrew it for the purpose of lighting his pipe. From too great reliance, in all cases, on the safety lamp, from neglect, and from various other causes, this lamp has disappointed the expectations of those most interested in its use, and experienced men now look for safety rather to improved methods of ventilation than to contrivances for lighting the mines. The general plan of ventilation now in common use will be understood from the following details.

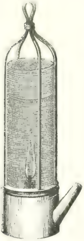
Fig. 576. THE DAVY.

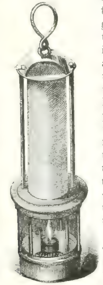
Fig. 577. IMPROVED DAVY.

When a seam is begun to be worked, there is, of course, only one available shaft for ventilation, and this is divided into two portions, as at *a b*, Fig. 578, for the ascending and descending currents: and as it is not safe for the men to be ever more than a few yards in advance of the course of the current, they begin working the seam with two parallel bords, connected at intervals by cross passages, which are successively stopped by wooden partitions, *c c c*, leaving no communication except through the one last opened, or that which is furthest from the shaft. Temporary partitions are also placed at *d d*, to direct the current to the very spots where the men are at work, as at w w. When the workings are more advanced, the direction of the current through every part, by *stoppings* or partitions, becomes a matter of no small complexity, as will be seen by the plan Fig. 579, where the arrows represent the course of the air from the downcast shaft, *a*, through all the galleries to the upcast shaft, *b*. It will be seen, that in most places the current is divided between the parallel bords; this is called *double coursing*, and its advantage is, that if any part of the mine is more fiery or dangerous than the rest, the current can there be confined to one course, and thus have its

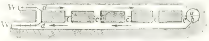

Fig. 578. VENTILATION WITH ONE SHAFT.

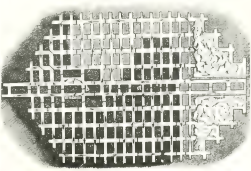
Fig. 579. PLAN OF A COAL-MINE.

velocity doubled; while in the parts containing least gas, the same current can be allowed to expand into three passages, which is called *treble coursing*. The double stoppings in Fig. 579, represent those in which doors of communication are required. These are made in pairs, in order that a person may pass through them, as a barge through a canal lock, without allowing the main bodies of air to communicate. To ensure this, they are sometimes made even treble, and a boy is placed in charge of each pair or set of three, whose duty it is to prevent them from being all opened at once.

As it is not safe to allow the foul air from the more fiery parts of the mine to come in contact with the fire at the bottom of the upcast shaft, which sets the whole ventilating current in motion, it is usual to divide the air, as it enters the mine by the shaft *a*, into two distinct currents, one of which proceeds through the passages *e e* into the safe parts of the mine only, while the other, *c c*, circulates through the fiery parts represented by the lighter shade, including the goafs, or old abandoned workings, which are always the most dangerous receptacles of gas. The purer current alone is allowed to pass through the furnace *f* before entering the upcast shaft *b*. The other current is conducted through *d*, and enters the shaft at a higher level by a tunnel cut obliquely through the roof of the seam, as in Fig. 580, where S represents the upcast shaft, B the impure current, and A the purer current, feeding the furnace, which, when thus constructed, is termed a *dumb* furnace.

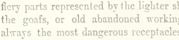

Fig. 580. A DUMB FURNACE.

In the Hetton colliery, in which there are two seams now worked, and one that has formerly been worked, there are two downcast shafts and one upcast, the former about 12 feet, and the latter 14 feet diameter. There are three furnaces at the bottom of the upcast, each about 9 feet wide and about 4 feet length of grate-bars. The depth of the upcast and one downcast is 150 fathoms; and of the other downcast 176 fathoms. The quantity of air introduced into the mine by the action of these furnaces was 168,850 cubic feet per minute, at a cost of about eight tons of coal per day. The rate of motion of the air was 1,097 feet per minute. This whole current is divided by splitting into sixteen currents, of above 11,000 cubic feet per minute, having on an average a course of $4\frac{1}{4}$ miles each. This distance is, however, irregular; the greatest length of course being $9\frac{1}{10}$th miles. The effective velocity of the current in the actual workings of the mine is much checked by the multiplication of passages, friction, and other causes, and is thus reduced to from 3 to 5 feet per second; the smaller quantity being about the maximum rate attainable by the natural current in a small mine, where there will generally be from 1 to 3 feet. It is estimated that the minimum quantity of fresh air required for the support of life in a mine is about 15 or 18 cubic feet per minute for each man employed.[1]

The goafs, or abandoned workings, are sometimes of vast extent, and are known to occupy from thirteen to ninety-seven acres of ground. They may be compared to enormous inverted bowls or basins, in which the inflammable gas from various parts of the mine accumulates, and from its lightness occupies, at first, the upper part of the goaf: as it increases in quantity, or even as the atmospheric pressure diminishes, it may suddenly fill the goaf and issue from its lowest edge as from the edge of an inverted bowl, and, mingling with the air of the mine, form an explosive mixture, thus giving rise to many sad accidents. Such appears to have been the origin of the explosion in Haswell colliery, Durham, in September 1844, by which ninety-five persons perished. Dr. Faraday, who, in conjunction with Sir Charles Lyell, visited the mine after the accident, with a view to devise some remedy against the recurrence of similar accidents, recommended that the goaf itself be ventilated. He thought it would not be desirable to attempt this by driving the contents of the goaf through any parts of the mine which are occupied by human beings; but that the goaf cavity might be exhausted of noxious air by means of a pipe, rising as high as possible, from four to eight or ten feet into it, and communicating at its other extremity with the upcast shaft.

Some interesting remarks respecting this explosion, and on the ventilation of coal-mines, were made by Dr. Faraday, at the Geological Section of the British Association, in 1845. Dr. Faraday remarked, that the more he pursued the inquiry into the means of preventing such accidents, the more he was disheartened at the apparent hopelessness of finding out any good general remedy. The explosions were not simply the effects arising from the mixture of gases, but from the combustion of the coal-dust and coal-gas which the first explosion made. In the fatal case at Haswell, the place where the accident originated had been ascertained, and the progress of the fire could be traced on the scorched beams and props of the galleries, and by the deposits of coke made from the coal-dust which the explosion raised. To this circumstance the great force of the explosion was due, and not to the first escape of gas. A similar explosion had been known to take place in a cotton-wadding manufactory, the whole atmosphere of the place being fired by means of the particles of cotton in it. Of all the workmen killed in the Haswell accident, perhaps not one was really burnt to death, but suffocated by the choke-damp. In one part of the workings, the explosion had produced sharp vibrations, like the firing of gunpowder; and in another, the burning went on slowly, like a common fire. But, although two panels were blown into one, and solid stoppings of brickwork thrown down, there was no indication of accident in the shaft. If the stoppings had not been blown down, and the supply of air had continued, the mine would have taken fire, and the men been burnt instead of choked. Since the late investigation, many hundred plans had been submitted, urging ill-considered and contradictory measures. Every part of the Haswell Colliery had been examined, accompanied by the mine-viewer, and recommendations had been received from the best informed men on the spot; and they were convinced that the conditions under which such accidents happen were so variable, that no general practical rule could be obtained. Far more information, however, was required. The plan of splitting the air courses was good, as far as the power of the upcast shaft admitted; but if carried too far, it would produce stagnant points, which could not be prevented by any arrangement consistently with the ever-moving condition of the works. The abolition of the use of gunpowder and lighted candles would, in some cases, double the price of coals. But the great source of danger was the mental condition of the miners. With regard to the present race this was so hopeless that nothing could be done for them. Although smoking was strictly forbidden, they had been known to contrive to light their pipes in dangerous workings even from the Davy lamp; and Dr. Faraday had himself, on one occasion, sat down with an open candle to watch the preparations for blasting, and when he inquired for the gunpowder, was told he was sitting on it. Dr. Faraday expressed his opinion of the safety of the Davy lamp when properly used, and of its being a complete and practical contrivance, to which he would willingly trust his own life, as he had already done on many occasions.[1]

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[1] Mr N. Wood's Evidence—Report of Lords' Committee on Accidents in Coal mines. 1849.

Various other contrivances have been made for promoting the ventilation of the northern coal-mines. In some cases, towers or chimneys have been built over the upcast and downcast shafts, with large cowls turned by vanes, as in Fig. 581, so that one may always present its mouth and the other its back to the wind. Mr. Brunton proposes to ventilate collieries by a modification of the fan, for which purpose immediately over the upcast shaft is constructed a hollow drum with radial compartments, through which the air is discharged with a degree of force due to the velocity with which the drum revolves. The drum, shown in section, Fig. 582, is 22 feet in diameter, with radial compartments, R C, each 6 feet long, and revolving 180 times per minute. "Taking 16 feet as the mean diameter of the compartments, the centrifugal force at 180 revolutions will be 88.5, which, multiplied by the weight of 6 cubic feet of air (= [illegible]ths of a pound), will give a pressure of 39lbs. on the square foot as the amount of rarefaction produced, which is much beyond what is obtained by the furnace. If driven to 210 revolutions per minute, it would produce a rarefaction of upwards of 50lbs. on the square foot; or, unconnected with any lengthened air-course (*i. e.* mere displacement), it would discharge more than 800,000 feet in a minute." This fan is very simple in construction; it moves in a well-oiled foot-pivot, and when at rest offers no resistance to air ascending from the pit. By connecting such an apparatus with a 12-horse steam-engine, the ventilation of the mine may be suddenly and powerfully increased; but for common use one-third of that power may be sufficient. In a trial made with this apparatus at Gelly Gaer Colliery, the rarefaction maintained in the upcast shaft was equal to 2½ inches of water, or 13lbs. on the square foot: this, of course, produced a strong current through the workings of the colliery, one of the air-ways of which, 20 yards long, has a mean area of only 9½ superficial feet; yet such was the power of the machine that 18,000 cubic feet per minute were propelled through this passage at a velocity of 32 feet per second, and afterwards, in its way to the upcast pit, through an opening of only 4 superficial feet area, at a velocity of 70 feet per second. By stopping the air in the downcast shaft, and setting the fan in motion, the whole of the colliery was subjected to a rarefaction equal to a sudden fall of the barometer of about two-tenths of an inch. This diminished pressure could be carried to a much greater extent, so as to draw off the fire-damp from the goaves and fissures, during the absence of the workmen and their lights.

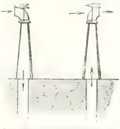
Fig. 581. VENTILATING COWLS.

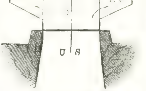

Fig. 582. VENTILATING DRUM.

The direct agency of steam has also been successfully employed by Mr. Goldsworthy Gurney in the ventilation of a mine. Instead of a fire at the bottom of the upcast shaft, a high-pressure steam-boiler is constructed, from which the steam issues in jets, heats the column of air in the shaft, and expels the whole column with great force, whereby a rush of air to supply its place is immediately made from the galleries of the mine. The high-pressure jets thus act as a force-pump in front, producing compression, and as a draw-pump behind, producing exhaustion. In fact, the power of producing exhaustion is quite remarkable, and promises to be of the greatest importance in the ventilation of coal-mines.

Next in importance in England to the Northern coal-field is the South Staffordshire coal-field. This is encircled on all sides by the new red sandstone formation; the coal-measures at the line of junction being usually broken suddenly off by faults, whereby the strata are brought up against the new red sandstone, the remaining portion of them being continued beneath it to an unknown extent. This is proved to

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(1) For this part of our subject relating to the ventilation of coal-mines, we are chiefly indebted to Mr. Tomlinson's "Treatise on Warming and Ventilation," published in Weale's Rudimentary Series.

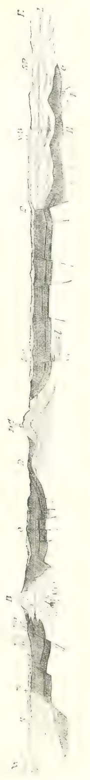
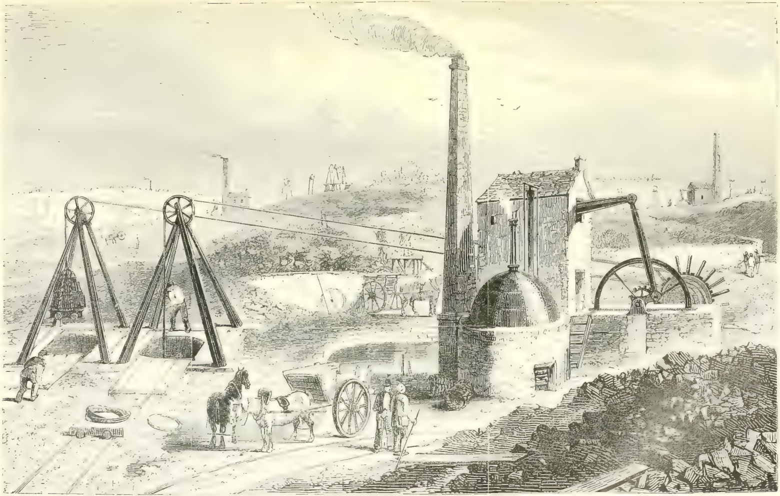


Fig. 583. SECTION ACROSS THE THICK COAL FIELD, SOUTH STAFFORDSHIRE.

L L Level of the sea.
S Sutton, near House Hill.
S Sedgley.
K King's Swinford: thick coal at 120 yards, further on at 190 yards, and at [illegible] yards at Barrow Hill fault. Strike NE. SW. Upcast 190 yards.
B Barrow Hill, 60 feet; coal charred and strata broken up by the trap. On each side the coal [illegible] and altered by the [illegible].
[illegible] not proved.
D Sedgley [illegible] cropping out.
D Dudley Castle [illegible]
D D Dudley [illegible] Wenlock limestone.
[illegible] 80 yards.
W [illegible] feet above the sea level.
T [illegible] Ten yard coal. t trap. c coal wedged.
[illegible]
W S Red Marl.

be the case at West Bromwich, and at King's Swinford, as shown at both the eastern and western limits of the field. (See section, Fig. 583.) This field forms an irregular oblong, bounded on the east by a line running from West Bromwich on the new red sandstone, by Walsall, on the Wenlock limestone, and continued westward of Lichfield to near Rugeley, where it comes to a point, the western boundary running thence nearly south by Cannock and Wolverhampton to Stourbridge; the southern limit being nearly coincident with the straight line drawn from Stourbridge to Hales Owen, and continued till it cuts the line of the eastern boundary, prolonged in a southerly direction. Its extreme length is 21 miles, and its general breadth from 6 to 7, thus forming a mere speck on the map; but from its enormous stores of mineral wealth, and the consequent density of its population, superior in importance to any other tract of equal extent in the kingdom.

"In traversing much of the country included within the above-mentioned boundary of red sandstone, the traveller appears never to get out of an interminable village, composed of cottages and very ordinary houses. In some directions he may travel for miles, and never be out of sight of numerous two-storied houses; so that the area covered by bricks and mortar must be immense. These houses, for the most part, are not arranged in continuous streets, but are interspersed with blazing furnaces, heaps of burning coal in process of coking, piles of ironstone calcining, forges, pit-banks, and engine-chimneys; the country being besides intersected with canals, crossing each other at various levels, and the small remaining patches of the surface-soil occupied with irregular fields of grass or corn, intermingled with heaps of the refuse of mines, or of slag from the blast-furnaces. Sometimes the road passes between mounds of refuse from the pits like a deep cutting on a railway; at others, it runs like a causeway, raised some feet above the fields on either side, which have subsided by the excavation of the minerals beneath. In one place, observing that the turnpike road sloped a good deal on one side, I asked the driver if it would not be repaired; to which he replied that they were still working the coal beneath it, and that they would probably wait to see if the road would not right itself by sinking on the opposite side, and so become level again. The geologist would find no country more instructive for the study of the subsidence of dry land. The whole country might be compared to a vast rabbit-warren. It is a matter of every-day occurrence for houses to fall down, or a row of buildings inhabited by numerous families to assume a very irregular outline, from what they call a *swag*, caused by the sinking of the ground into old workings. It is often a serious matter to find a sound site for a church or school-building. . . There is an instance in the parish of Sedgley of a church and parsonage-house, recently erected, composed of wooden framework, which will admit of their being screwed up into the perpendicular again whenever they may be thrown out of it. Cellars beneath dwelling-houses are occasionally filled with choke-damp, arising from old work-



COAL.—WHIMSEY, OR ENGINE DRAWING COAL IN THE STAFFORDSHIRE COLLIERIES.

ings, to a degree that makes it dangerous to enter them. On one occasion, a gentleman remarked that perhaps I was not aware that the steps by which I entered his house (in a town) were built on an arch covering the mouth of an old coal-pit. Early potatoes for the London market are raised in ground near Dudley, heated by steam and smoke, which proceed from an old colliery which has been on fire for many years, and which may be observed bursting through the crevices of the rock on the side of the road close to the town."[1]

Fig. 584. TOTTERING HOUSE, SOUTH STAFFORDSHIRE COAL DISTRICT.

The geological features of this formation have been developed by Sir R. I. Murchison, in his magnificent work, "The Silurian System," (4to, London, 1839,) in which he has developed a distinct series of geological formations which, being best exhibited in South Wales, the country of the ancient *Silures*, the term *Silurian System* has been applied to them. By means of these researches the important fact was determined that the Dudley limestone is an isolated protrusion of two Silurian limestones, and not a portion of the carboniferous, or mountain limestone, to which its position, rising immediately as it does from below the coal-measures, had caused it to be referred. "Notwithstanding that this field contains the thickest seams of coal in England, its associated strata are of very small dimensions compared with the equivalent series in other parts of the kingdom. The millstone grit is scarcely represented; and the mountain limestone, the usual base of the system, as well as the old red sandstone, are entirely absent. The absence of these formations and the immediate contiguity of the coal-measures, and the Dudley or Wenlock limestone, one of the Silurian rocks, constitute a remarkable and important character of this coal-field. These ancient Silurian rocks, however, the real substrata of this coal-field, instead of appearing in the regular order of their superposition, rise up irregularly like islands through the coal measures near Dudley and Sedgley and form the eastern boundary of the field near Walsall." (See the general section across the field, Fig 583.)

The Silurian system forms a complete succession of fossiliferous strata interpolated between the old red sandstone, and the oldest slaty rocks. It consists of four principal divisions, beginning with the more recent: 1, the Ludlow or Sedgely limestone; 2, the Wenlock or Dudley and Walsall limestone; 3, the Caradoc sandstone; and 4, the Llandeilo flags. This Silurian is separated in the geological series of formation from the deposits of the carboniferous era by the vast series of the old red sandstone system; and thus the coal measures of England are usually included between the two great red-coloured systems of rocks, viz.—the old red sandstone, below; and the new red sandstone, above them. This last system begins immediately below the lias in a descending series, with 1, Saliferous marls; 2, Red sandstone and quartz on conglomerate; 3, Calcareous conglomerate expanded in Durham into the magnesian limestone; 4, Lower new red sandstone, which immediately overlies the coal measures. The great thickness of these lower sandstones was proved in the parish of West Bromwich by sinking through them to the coal. "These workings descend through a variety of red spotted sandstones, marls, and courses of calcareous grit and conglomerate. It was well known that the coal seams of the adjacent Dudley coal-field do not deteriorate or thin out near these works, but are simply lost by faults. The existence of the upper beds of coal having been previously ascertained by borings carried down to a depth of more than 700 feet below the surface, they and the lower beds have since been reached by sinkings, and are now in full work. . . . The success of the attempt was derided by many of the miners of the adjacent coal-field, it having been till very recently the prevalent belief that this red sandstone entirely cut off the coal, and that the latter would never be found under the former; but this notion is fast vanishing, and will soon be entirely removed.

"Owing to the great disturbances to which that part of the field which contains the ten-yard coal has been subjected, whether by the upheaving of the trap and Silurian rocks, or by great dislocations, the same measures are reached at very various levels in different localities. Thus in some situations shafts are sunk through shale and clunch with bands of sandstone to depths exceeding 100 yards before traces of coal are met with; while in many collieries, as near Wednesbury, all the overlying seams of coal and coal-smut which connect the coal measures with the lower new red sandstone have been removed, or have thinned out, and the ten-yard coal rises at once to the surface. It was this natural out-crop of the thick coal which led our ancestors to work it in open quarries. It has been stated that the lower coal and iron-stone measures crop out from under the ten-yard coal, and extend into the great Wolverhampton field. In their spread to the north, however, these strata assume very different characters from those which they possess when they underlie the thick coal in the portion of the field south of Bilston and Wednesbury. In most of the works which have hitherto been established in the region of the ten-yard coal, three courses only of workable iron ore have been ascertained; whilst in the Wolverhampton district six valuable bands are wrought. By a band is meant one of those groups of concretions in which two or more courses of iron ore are often separated from each other by shale or clunch."

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[1] Report of the Commissioners, &c.

The operations of getting out the ten-yard coal, which is peculiar to South Staffordshire, will be understood from the following description, and by referring to the large engraving.

The first class of labourers are the *holers*, seen at work in the centre of the picture. These men undermine, or make a hole, under the mass of coal, by cutting out with light picks the bottom measures, building up small supports called *cogs* of stone to support the mass of coal under which they are at work. A sufficient extent of coal having been thus undermined, they next cut upwards a cavity between the mass of coal which is intended to fall and that which is intended to stand, as a pillar to support the roof of the mine. This cutting, or separating the coal from the pillars, must be performed on both sides of the mass which is to be let fall, and also at the end where it joins on to the remaining solid mass. The mass is not, however, completely separated from the pillars, but small supports, called *spurns*, are still left, which connect the mass to be thrown down with the pillars. The coal is cut through until the parting is reached which forms a natural division of the lower measure from the next above it; or sometimes two measures are cut through at once, but always to a natural parting, the cutting being made perpendicularly up the face of the pillar, but any shape, so as just to admit the pick and the arms of the workmen on the side of the coal to be thrown down, so that a vertical section of the cutting would present the appearance shown in Fig. 585. After the cutting is completed and the men have withdrawn, the most skilful, armed with a long pricker, cuts and tears away the spurns and the cogs, when the mass of several tons falls together. In this way, after holing out the under part of the coal, all the rest of the measures are brought down successively by cutting.

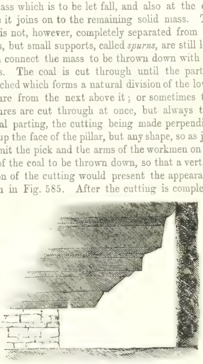
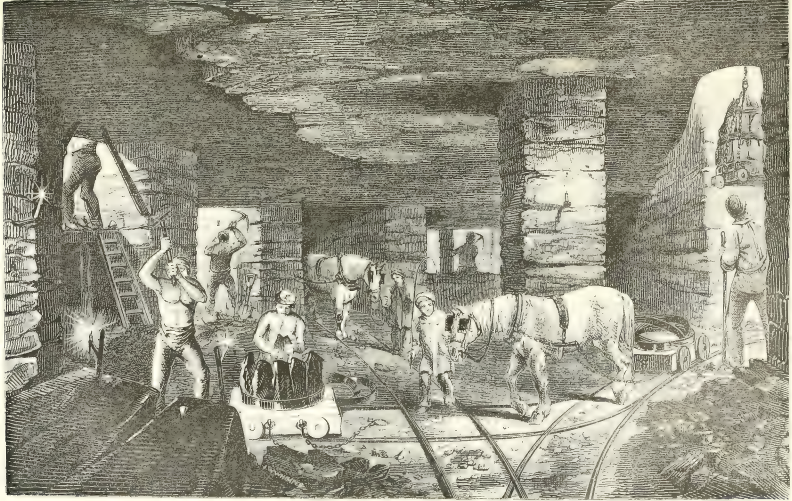


Fig. 585. SEAM OF TEN-YARD COAL.

The men engaged in this work are paid by the *stent* or *stint*, a certain number of feet of work; which, however, varies in different mines: it was stated by one workman to be 2 yards in, 3 feet wide, and 2 feet 3 inches high. This will bring down from 8 to 10 feet thick, the parting being called hardstone. The stint for cutting is 3 yards long, and a yard thick, 27 feet on an average. "One such stint is called a day's work, whatever number of hours it may take to perform it. Thus, supposing work plentiful, and the coal of a soft quality and easy to work, a man may do 8 or 9 days' work in a week; or if there is not a brisk demand for coal, he may get through his day's work in 8 or 9 hours, and have the rest of the day at his own disposal. This it is which makes the employment of a pikeman to be generally considered in ordinary times the best, and the object of the ambition of the young and vigorous miner, though it is evident on looking at the view, from the position in which the pikemen are represented, and the confined space and constrained attitude in which they have to wield their picks, that 8 or 9 hours of such work is as much as ordinary strength can support. Still more evident is this to any one personally visiting a mine, and seeing their naked and reeking bodies shining with the sweat, as if oiled; excepting where a coating of dust from the coal mixing with the perspiration has formed a crust on the skin. In the close atmosphere caused by the animal heat, added to that of the candles, and to that due to the depth of the mine, the rapid blows of the picks are intermingled with suppressed groans, such as are uttered by paviours in England, or by woodcutters in France, proceeding from the labourers seated far in beneath the impending mass of coals, giving a vivid idea of the great physical exertion to which every muscle is urged."

The next class of miners to the pikemen, are the various labourers comprised under the general name of *bandsmen* or *bondsmen*, from the circumstance of their working in connexion with the *band* or flat rope, by which the coal, &c. is hoisted to the surface. These men work by the day of 12 hours, and are usually not *stinted*, or paid by the piece. Their various occupations are shown in the large underground view. The *turners out* break the huge masses of coal which have fallen into manageable sized pieces, which the *loaders* place upon the skips, and the *pitchers*, lads of 12 to 15, arrange and surround with iron hoops, which the *horse drivers* then take away to the bottom of the shaft along iron tram-ways, where the *hanger-on* attaches it to the hook and rope, or chain, by which the engine hoists the load to the surface. In the process of holing out the coal, or undermining it, and afterwards at each successive fall of coal, a quantity of small dust coal, in general not thought worth raising to the surface, is produced. It is called *slack*. It is the office of certain stout boys, called *dirt carriers*, to carry this back in baskets or iron trays with handles from where the men are working, to the empty space behind them, commonly called the *gob*. Behind these dirt



COAL.—BRADLEY MINE, NEAR BILSTON. (GETTING OUT THE TEN-YARD COAL IN THE STAFFORDSHIRE COLLIERIES).

carriers, there is the *clanser* or *cleanser*, who separates the stony partings from the coal where they occur, and builds them up in the gob.

The following account of a visit by Mr. Tancred to the Heath Colliery, West Bromwich, will form an appropriate conclusion to this notice of the thick coal of Staffordshire.

"This pit is very interesting in a geological point of view, having been the first attempt to find the ten-yard coal beneath the lower new red sandstone, by which this coal-field was till then commonly supposed to be bounded on three sides. This attempt therefore having been successful, corresponds in importance to the finding the Durham coal extending beneath the magnesian limestone. The sinking was so expensive here, that there is but one shaft for winding, and one for pumping, which is not advantageous for the engine, as there is no counterpoise of one skip going down, and the full one up. There is an engine of 50-horse power for pumping, and a 30-horse for drawing coals; 30 cwt. is about the average lift of coal, which is raised in 4 minutes, and the skip returned in 3 more.

"On arriving at the bottom, we found quite a summer temperature from the depth, 308 yards. It is very dry, and the main-gate or road is lighted with candles permanently fixed along the sides, an expense which butties do not usually allow, but which is said to prevent accidents. The horses did not seem any way ill-used, as it is said they would be if they were not the butty's own property; one had an eye knocked out, but it was purely accidental; and they showed me how they understood their work just like human beings. The coal here is dragged by a pair of horses on a sledge, from the place where the skip is loaded to the main road. In the main road is a wagon, as it is called, being a square truck running on four low iron wheels, on a tram-road. This tram-road being much below the level of the ground on each side, by just about the height of the little wagon, the skip of coal, which is dragged along like a sledge, is drawn across the road where the wagon stands, and so slides on to the wagon. One horse now draws what two had done, and the last part of the journey it is let to run by itself towards the shaft down an inclined plane, being checked by being hooked on to an endless chain, which, as it runs round a roller, is stopped with a break by a man stationed at the top of the descent for that purpose.

"We saw a large extent of coal *undergone*, that is, the first two operations performed, and the two lowermost strata of coal got out: these are the benches, divided from the next by the bench bat; and the second, slipper and sawyer, the first holed out, the next cut down, leaving a space of 6 feet 6 inches or 7 feet between the floor and our heads. The cleanser was carrying away the heavy *hardstone* which divides the fourth and fifth seam, from some coal which had very lately fallen, before the band or bondsmen came to fill it into the skips. In other places, we saw the turner-out breaking up the great masses of many tons weight of coal into manageable bits, and the labourers, or *band*, filling the coal with hands or shovels into the pit.—We saw a great quantity of coal *undergone*, that is, the first two or three strata to the height of 7 feet taken out, so that the rest had only to be *cut*, or separated at the sides from the pillars, which are left to support the roof, in order to be brought down. When a quantity of coal has fallen after the first holing, it affords a footing to the pikemen, from which they are able to reach high enough to cut into the next stratum. When the height becomes too great, they are obliged to fix scaffolding to reach their work: and so this cutting is much more severe labour than holing, and they often take off their trowsers and work quite naked, the sweat streaming off their bodies like rain, as a pikeman expressed it, and of course the coal dust adhering to the whole person, as it does, indeed, when he is only naked to the waist. It is particularly hard work from the heat which is experienced when half the body is confined during such violent exertion between the two masses of coal, only just wide enough apart to allow the play of the arms, and where the heat is very great from the air not reaching into such places. To understand this cutting, suppose the ceiling of a room were a stratum of coal, like that called *strong coal*, nearly 4 feet thick. The pikeman begins to dig his pick in, and by repeated blows upwards, to cut a channel about 1 foot wide up against the side of the wall. Now if he were to cut all along the whole length of the room and deep enough, the ceiling would have no support, and would consequently give way and fall, crushing all living things beneath it. He therefore leaves, at every 6 feet, perhaps, part of the coal uncut, called *spurns*, which act as supports to the mass something like corbels supporting the beams of a roof, or flying buttresses in gothic architecture. When the pikeman has cut away a channel a foot broad, and so deep that he cannot any longer use his pick with effect, he is obliged to enlarge the lower edge of his cutting, but the deepest part he keeps as narrow as possible, to save labour. As he must keep his wall on one side perpendicular, the channel is straight on one side, and on the side of the coal which is to fall it slopes towards the wall, as in Fig. 585. Having been cut through to the full thickness of the strong coal, viz 4 feet, on both sides of the mass to be brought down, and spurns being left at proper intervals to keep it up whilst the men are at work at cutting, the next operation is to take away these spurns and so let the coal fall, which is called *throwing* the coal. This service is one of danger, and requires much experience and skill. The spurns are cut and pulled to pieces with long-handled instruments called prickers, and the men must often spring back if there is an appearance of the mass coming down. This business of throwing the coal is often done by a few men at night to prevent danger to the rest.[1] The different sorts of cutting, according to the height of the strata

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(1) The danger to the men after this throwing or falling of the coal, is thus explained by one of the witnesses. It should, however, be remarked that the *doggy* is the foreman of the pikemen and that the *butty* is the middle-man, who takes the contract for a piece of work from the proprietors, and gives it out to the men "After a fall of coal, it's worse than a field of battle full of soldie

above the floor of the mine, and the holing, as well as driving the air-courses or gate, roading, &c., are done by different stints or measured quantities, according to their difficulty. The pikemen universally prefer holing as the easiest work, though in this they have to sit on the ground in a place only 2 feet 3 or 4 inches high, where they cannot straighten their neck, far in beneath a mass of coal some 28 feet thick There you may stoop down and by the glimmer of their candles see them, naked to the waist, plying their picks, their bodies smoking and appearing as if oiled with the perspiration, and a coat of coal-dust adhering to the skin and hair of the head. All the time you hear, issuing from this low-roofed cavern which they are hewing out, stifled groans, which they utter as they rapidly repeat the blows of their sharp picks against the black mass, which is splintered and flies in all directions. The various works going forward in these subterranean avenues produce a development of the muscles of the chest, back, and arms, which could not have been surpassed in the athletæ, who won the laurel-wreaths at the Grecian games. The noxious gases which they are now and then subject to inhale, produce paleness and loss of appetite; otherwise, were it not for the direful accidents to which they are exposed, the thick-coal miners could not be surpassed in healthiness by any other class of workmen. The exhausting nature of their labour doubtless requires for its performance the vigour of manhood still unimpaired by the advance of old age, and a nutritive diet to recruit the frame; but with these conditions, the healthiness of the occupation is proved by recoveries from appalling accidents, which to surgeons unaccustomed to practise amongst colliers appear miraculous.

"The ventilation of this mine is cleverly managed by means of a tunnel extending from the pumping shaft, under the boiler furnace, to the stalk of the furnace fires, by which a very strong current of air is always drawn from the mine. For the ventilation below ground, narrow galleries are cut in the coal, used only as air courses, and there are no boys employed to keep air-doors."

The accidents in the thick-coal pits are very numerous. According to one return, for every 100 men employed 72 accidents occur annually, of which five are fatal. The accidents are almost entirely bruises and broken limbs, arising from the falling down of the coal and heavy materials of the mine. These accidents can only be obviated by a safer system of extracting the minerals by a liberal supply of timber and lights, and by prudence and caution on the part of the workmen and overlookers. Such accidents are most numerous in mines where middle men or *butties* are allowed: they take the contract for a piece of work from the proprietor and give it out to the men, and it is their interest to do the work as cheaply as possible, without any regard to the safety of the men. A few honourable exceptions are, however, mentioned in the Parliamentary Report. One of these is the case of a religious and conscientious man named Mason, whose pit had for a long period been almost entirely free from accidents, and the reason assigned by the men was, that they met together to pray every day in the dinner hour. "About one o'clock the drink goes down the pit, and if a man is not at the place of prayer in 10 minutes after, he forfeits his drink. They sing and pray, and ask a blessing on what they are going to have, and then they sit down in the road and eat their dinner and drink the beer, and after dinner one reads out of the Scripture and explains it, and tells the others what the preacher has said about it. Sometimes they get God's Spirit amongst them very much, and sometimes less so." Very few of these men could read, and it was stated that, "a man would not be allowed to join in singing and praying unless he was thought to be living as a man ought to do."

There are very few accidents arising from explosions of fire-damp, as this gas appears to be engendered by the Staffordshire coal much less abundantly than in most other fields, and that which is produced is carried off by the ventilation. The men work with open candles.

The methods of working collieries in other parts of Great Britain were formerly very objectionable, on account of the narrowness of the ways, and the employment of women and children. The evils are stated at length in the reports which have already supplied us with information.[1] It will not be necessary to notice them in detail, since the evils complained of have been greatly mitigated by the Act of Parliament (5 & 6 Vict. c. 99).

It may readily be supposed that the nature of the employment and the condition of the miner, must to a great extent depend on the thickness of the seam of coal, and the consequent dimensions of the subterranean roadways, together with the ventilation, drainage, and temperature of the mine. These dimensions and facilities must of necessity greatly vary when it is considered that the seams of coal actually worked in various parts of the kingdom, vary from 10 inches to 10 yards in thickness. When the seams of coal are thick, the roads made for conveying the coal from the

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to be forced to go to draw the coals before it's settled and made secure. And, perhaps, the doggies will say, 'Go in, we must have these coals drawn out.' That man you were with in our pit, [the doggy,] is as worthy a man as ever stood in shoe-leather, and would not put a man to work in a place that he did not know was safe for any thing. It's always made secure for us."

Another witness says:—"I was working last night at the wing coal. It's safer at night, because when the horses, and rings, and skips are making a noise you cannot hear the coal when it begins to stir. If this had been done in the day, and the band perhaps waiting for it, the butties will not give a man time to prick it with the long prickers, but will say, 'Come, bring the band here, I see it's safe,' and perhaps a piece falls and kills a man. When I worked at Hocker Hill in Tipton, I remember a man being killed by the band being hurried under the stuff where the roof was rotten, and a piece of rock fell on him and knocked a hole in his side. . . I really think if they had looked before they ordered the band in, this man's life might have been saved. The doggy in our pit is a very good one for that, he'll come up to tell you to mind to be careful, and he will have timber up to it."

(1) Reports from Commissioners, 1843. Midland Mining Commission. First Report—South Staffordshire.—Children's Employment Commission. First Report—Mines, 1842.

workings to the foot of the shaft are always spacious. Little difference will be felt in seams of different thickness, as long as this is not less than from 5 to 6 feet; but as the thickness of the seam diminishes, it rapidly becomes more expensive in proportion to the quantity of coal to be procured, to make the roads for carrying on the operations of the mine of a convenient height, and the cost of doing this is materially affected by the nature of the strata both above and below the seam. If the seam be very thin and the coal of excellent quality, and the strata above and below of such a nature that they cannot be removed without great expense, the roads are in such case made no higher than are absolutely necessary for getting the coal and conveying it to the foot of the shaft. Under such circumstances the operations of the miner are most laborious and injurious.

It is stated that no coal-mine can be worked with tolerable convenience or comfort to the work-people, if the main roads are less than from 5 to 6 feet in height, and the side roads 2½ feet. When the roads are 6 feet high and upwards, there is ample space for carrying on the operations of the mine, and horses can be used for drawing the coals from the workings to the foot of the shaft. When the main roads are 4½ feet high the mine may still be rendered sufficiently convenient for the work-people, and ponies or asses may be employed for drawing the coals. But when the main ways are under 4 feet, the coals can no longer be conveyed by ponies or asses, or even by adult or young men: they can only be conveyed by children. It appears, however, that in many mines the main gates were formerly only from 24 to 30 *inches* high, and in some parts the passages did not exceed 18 inches in height. In such a case very young children were employed, and even they had to work in a bent position of the body.

In the West Riding of Yorkshire children were employed in attending to the trap doors, driving the horses along the main gates, attending to the jenny, and conveying the coals from the bank faces to the shaft where there were no horses, and to the tram-roads where there were any. "The trappers sit in a little hole scooped out for them in the side of the gates behind each door, where they sit with a string in their hands attached to the door, and pull it open the moment they hear the corves (carriages for conveying the coal) at hand, and the moment it has passed they let the door fall to, which it does of its own weight. If anything impedes the shutting of the door, they remove it, or, if unable to do so, run to the nearest man to get him to do it for them. They have nothing else to do; but as their office must be performed from the repassing of the first to the passing of the last corve during the day, they are in the pit the whole time it is worked, frequently above 12 hours a-day. They sit, moreover, in the dark, often with a damp floor to stand on, and exposed, necessarily, to drafts. It is a most painful thing to contemplate the dull dungeon-like life these little creatures are doomed to spend,—a life for the most part passed in solitude, damp, and darkness. They are allowed no light, but sometimes a good-natured collier will bestow a little bit of candle on them, as a treat. On one occasion as I was passing a little trapper, he begged me for a little grease from my candle. I found that the poor child had scooped out a hole in a great stone, and having obtained a wick, had manufactured a rude sort of lamp; and that he kept it going as well as he could by begging contributions of melted tallow from the candles of any Samaritan passers-by. To be in the dark, in fact, seemed to be the great grievance with all of them. Occasionally they are so posted as to be near the shaft, where they can sometimes run and enliven themselves with a view of the corves going up with the coals, or perhaps, occasionally, with a bird's-eye peep at the daylight itself; their main amusement is that, however, of seeing the corves pass along the gates at their posts. When we consider the very trifling cost at which these little creatures might be supplied with a light, as is the case in the Cumberland collieries, there are few things which more strongly indicate the neglect of their comfort than the fact of their being kept in darkness,—of all things the most wearisome to a young child."[1]

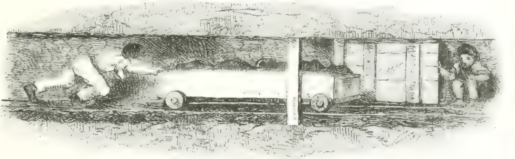

FIG. 356.—TRAPPER IN THE LANCASHIRE AND CHESHIRE COAL-PIT.

The chief employment of young persons in the coal mines of this district was to convey the coals in corves either from the workings to the horse-ways, or where the main-roads were not high enough for horses, to the foot of the shaft. The corves are oblong wagons on small wheels of 9 or 12 inches in diameter, running on railways. They vary in size, carrying from 2 to 10 cwt. of coal, but the commonest size in the thickest beds of coal are made to hold 6 cwt. of

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(1) Report of J. C. Symons, Esq.

coal, and weigh about 2 or $2\frac{1}{2}$ cwt. themselves, making a weight of about 8 cwt. in all. The operation of propelling these corves, called *hurrying*, and in some places *tramming*, was done by placing both hands on the top rail of the back of the corve, and pushing it forward, running as fast as the degree of inclination of the road, or the strength of the hurrier, would permit. The hurriers were hired and paid by the colliers; they were often girls of all ages, from 7 to 21. Their work was not confined to the hurrying of the corves backwards and forwards along the gates. When the hurrier arrived with his or her empty corve at the bank-face, it had to be filled; and when the coal had to be riddled or sieved, the hurriers assisted. The collier shovelled up the smaller coal and threw it into the riddle, which was held by the hurrier, who then shook it, and threw the coal which remained into the corve. When this was nearly filled it was *topped* with large coal, and the hurrier then started and hurried it down to its destination, and returned back again as soon as possible with an empty corve. Sometimes when the collier had not got sufficient coal by the time the hurrier returned, the hurrier took the pick with which the coal was hewn, and helped to *get*. By this means the art of getting was usually learnt, and the hurrier by degrees became a collier, and at 18 or 19 left off hurrying altogether. Getting is performed first by making a horizontal cut underneath the coal it is intended to get; this is called *holing*, and as it has to be done very low down, the collier is obliged to kneel, and often to lie on one side in a very constrained posture, to work; next, deep vertical cuts are made in order to release the block from either side at given lengths: it is then detached from above by means either of gunpowder or wedges. Girls regularly performed all the various offices of trapping, hurrying, filling, riddling, topping, and occasionally getting.

The seams in many of the mines about Halifax are not more than 14 inches in thickness, and rarely exceed 30. The colliers are obliged to work lying their whole length along the uneven floor, and supporting their heads upon a board or short crutch. When they are able to obtain a little more space, they work sitting upon one heel, balancing their persons by extending the other. In these low, dark, heated and dismal chambers, they work perfectly naked. The corves drawn by the hurriers weighed from 2 to 5 cwt: they were mounted on four cast-iron wheels, 5 inches in diameter, but not moving on rails. These corves were dragged by children through passages in some cases not more than from 16 to 2[illegible] inches in height: they buckled round their naked persons a broad leather strap, which was attached in front to a ring and about 4 feet of chain, terminating in a hook.

We give these details as a very moderate sample of the evils which had to be remedied. There were other and greater evils, which it is happily not necessary now to describe. In some cases much of the suffering resulted from the coal owners continuing to work their mines in modes which had become obsolete in all other districts. "A little reflection would have prevented a vast deal of unnecessary and painful labour in the working of edge-seams in Scotland; for instance, in South Wales (where the stratification is almost vertical), on the sea coast, at Briton-ferry, and in the Anthracite field in Pembrokeshire, *coal-bearing* as practised in Scotland is entirely unknown. The coal is transported from the different workings by successive windlasses, or balances working on inclined planes, which plan entirely removes the necessity of employing female labour. In the county of Pembroke, for example, the field or bed of coal (anthracite) is in many workings highly inclined. Suppose a vein to lie at an angle of 45° or even 55°, windlasses are fixed at convenient distances on the incline of the vein, by which means (if the mine is worked by adit or level, and *above* the adit) the coal after being brought from the stalls to the stage of the windlass in carts or skips, is dropped by the chain of the windlass down the incline to the level road, and the empty carts are worked up to the stage on which the windlass is fixed by the opposite chain of the windlass. If, on the contrary, the coal is worked to the dip, the coal is in a similar manner worked *up* to a convenient stage by windlass, and then taken by shaft to the surface. The windlasses are worked by women, and their labour is certainly severe, though only of 8 or 10 hours' duration. Fig. 588 represents the carts or skips of coal descending the incline in a pitching vein to the level of the road, after their arrival at which they are drawn by horses to the shaft, or to the mouth of a level. Fig. 589 represents girls winding coal from the workings in the dip.

Fig. 588. PITCHING VEINS.

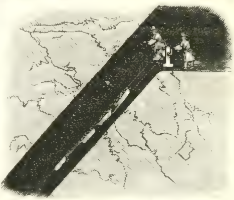

Fig. 589. [illegible] IN SOUTH WALES.

The Act of Parliament already referred to has put an end to these evils. From the time of passing the Act, no female, other than such as were so employed previously, was to work in any mine or colliery; and after three months from that date, no female under eighteen years old should be so employed; nor any female whatever after March 1, 1843. After this latter date, no males were to be employed under ten years of age; no person to be apprenticed under ten years of age, nor for longer than eight years (except in the case of engine-wrights and others who are only occasionally at work under-ground). Where there are vertical or other shafts, no steam or other engine to be entrusted to the care of a person under the age of fifteen; in the case of a windlass or gin, worked by a horse or other animal, the driver to be considered the person in charge. After three months from the passing of the Act, proprietors of mines or collieries not to pay workmen their wages at any tavern or public-house. To enforce the observance of these regulations the following arrangements were made:—Inspectors of mines and collieries, appointed by the Secretary of State for the Home Department, are empowered to enter and examine any such works, and to report concerning them to the Government; any proprietor violating the law as to the age and duration of apprenticeship is subjected to a fine varying from 5*l.* to 10*l.*; parents or guardians misrepresenting the age of children so employed, are fined 40*s.*; a neglect of the clause as to the care of the shafts, and also of that relating to the payment of wages, subjects the offender to fines varying from 5*l.* to 50*l.*

In many of the coal-mines of England where fire-damp is not very common, ventilation is defective. According to the evidence of Mr. Woodhouse, mining overseer of the Moira collieries, Leicestershire, there are many drawbacks from the profits of collieries arising from a bad and defective system of ventilation. He says:—"The improved system adopted in the collieries on the Tyne and the Wear, of dividing the workings into districts, and so obtaining a current of fresh air in every division, may in many cases be adopted at a trifling expense in these counties; and although the extent of the workings in general bears no proportion to those in the collieries in the north, the principle remains the same, and the result would be favourable in a corresponding degree. It may be urged that the immense quantity of gas given out of the coal in the north has called for the improved system there, which is, probably, the fact; but there are many advantages to be derived from good ventilation, beyond the mere prevention of explosion. In pits with a rapid circulation the men respire more freely, the road ways are kept dry and repaired at less expense, and the timber lasts longer *by years*, and therefore it is a matter of strict economy to ensure a good ventilation. The men suffer most materially from working in an impure atmosphere. In some mines the air can scarcely be perceived to move at all, a thick mist or fog pervading the whole pit; which is caused partly from fermentation in the wastes and old works, partly from the lights, and partly from the heat and effluvia from the horses and men. This, with a large proportion of carbonic acid gas, forms an atmosphere that none but colliers, who are accustomed to it, could endure, but which has the effect of shortening their days."

With respect to *drainage*, some pits are naturally very dry; others cannot be kept so without constant care, and much expense. Various methods of drainage are adopted, according to circumstances; such as bringing up the water to the surface in buts worked by machinery, or by successive lifts of pumps, or by collecting the water in a sink or sump at the bottom of one of the shafts, and then drawing it up in buckets by the engine when it is not engaged in raising coals; or by sinking a shaft on purpose, in which is placed a series of pumps for raising the water from one lift to another, until from the highest pump of all, which brings water to the surface, a perpetual stream is made to flow. Whenever the floor of the pit lies in such a way that the water will flow to the place to which the lowest pump descends, then the pit can be effectually kept dry.

Neglect of drainage renders the mine very miserable for the work-people. Thus, in speaking of the Derbyshire pits, the commissioner says that some of them are so wet, "that the people have to work all day over their shoes in water, at the same time that the water is constantly dripping upon them from the roof. In other pits, instead of dripping, it constantly rains, as the people themselves term it, from the roof, so that in a short time after they commence the labour of the day, their clothes are drenched, and in this state, with their feet also in water, they work all day. The children, especially,—and in general the younger the age the more painfully this unfavourable state of the place of work is felt,—complain bitterly of this, and it must be borne in mind that it is in this district that, according to the evidence, the regular hours of a full day's labour are 14, and occasionally 16." The sub-commissioner, speaking of the same district, says:—"I have met with pits where it rained so as to wet the children to the skin in a few minutes, and at the same time so hot that they could scarcely bear their clothes on to work in, and in this wet state they had to continue 14 hours, and perhaps had to walk a mile or two at night without changing or drying their clothes."

Coal-pits are almost always warm, and in general the deeper they are, the warmer. By proper ventilation the heat can generally be so regulated as to render the temperature pleasant. When cold in the main roads the heat is often oppressive in the side gates and at the workings. Oppressive heat indicates imperfect ventilation. It is stated that in the mines of the Yorkshire coal-fields the thermometer stands in the main roads at from 50° to 60°, in the side roads from 60° to 65°, and at the workings from 64° to 72°. In the deep mines of the northern coal-field the temperature is considerably higher. In one of the Hetton pits in South Durham, the temperature was found to be 66° at the bottom of the shaft, and 70° in the workings; but in the Monkwearmouth colliery, the deepest in the northern coal-field, the average temperature ranges from 78° to 80°, and in some parts it occasionally rises to 89°.

We conclude this article with a few general details on the subject of collieries. In the Northumberland coal pits, when the coals have been brought to the bottom of the shaft, and placed upon the cage, the signal to wind them up is given to the engine-man at the surface by means of a wire led down the shaft attached to a hammer above. When the hammer gives one stroke, the engine-man knows that coals are to be drawn up; when three strokes, that men are to be drawn up, and so on. The usual method of winding is with cages, guided in the shaft by wooden conductors, which reach from the pit bottom to the pit-head pulley, and are stayed where required. Cages are platforms attached to the ropes, for carrying the loaded hutches; they have guides for the conductors to work in, whereby the ascent is made safe and steady. The cages may hold two hutches, side by side, or one above the other; but in deep windings, and with a large supply of coals, three or four hutches may be taken up at once. There should also be a safety apparatus, for releasing the cage in case of overwinding, or for stopping its descent should the rope break. The safety apparatus of Messrs. White and Grant, of Glasgow, is said to be efficient. (See Figs. 590, 591, 592.) Fig. 590 shows the manner in which certain eccentric toothed pinions, B B, act upon the wooden conductors *a*, should the rope break, or become disengaged by the catch *h*. The pinions are connected with spiral springs. C is the slide-bar from which the cage is suspended, and to which are attached the springs *f f*, while *h* is the catch, which disengages the rope in case of overwinding, or when brought in contact with the pit-head frame *k*. The use of the springs *f f* is to ensure the action of the pinions B B; they also prevent a sudden strain from being put upon the rope when the load is lifted, which is of importance where wire ropes are employed. Some other contrivances of this kind will be noticed under MINE—MINING, Sec. vi.

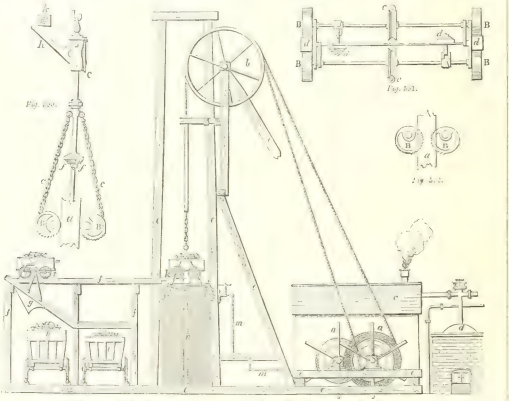

Fig. 590.

Fig. 591.

Fig. 592.

Fig. 593. Screening and Tipping.

Fig. 594. Arrangements for Winding.

The general arrangements for winding, screening, and carrying away the coals, are shown in Figs. 593, 594, in which *a a* are the drums on which the ropes wind, *b* the pit-head pullies; the drums are placed on different shafts, in order that the ropes may always be made to bend one way, for it has been found that when both drums are on the same shaft, the one that overwinds lasts longest. *c* represents the engine-house, *d* the boilers, *e* the engine and pit-head framing, *k* the cage, *n n* the conductors already referred to, while *l l* are folding boards, so arranged that when the cage is raised from the pit, it shall open them, and immediately shut for it to rest upon them. By this contrivance the banksman is enabled to draw the loaded hutch from the cage on to the platform *f*, and replace it by an empty one. The folding boards are again opened, to allow the cage to pass through; this is done by the engine-man, by means of the rods *m m*. At *t* is a tumbler for emptying the hutches into the screen *g*, and is so arranged that when the loaded hutch is run into it, the extra weight beyond the point of suspension throws the hutch into the position snown by the dotted lines. There is a break for controlling this movement, and when the hutch is emptied, and the friction removed, the machine falls back into its first position, and the empty hutch makes way for the full one. By means of the screens the dross is separated from the coal, the former being collected in the wagon *h*, and the latter in *i*.

British coal was well represented in the Great Exhibition of 1851. The coal trade of Northumberland and Durham was illustrated by maps and sectional drawings of the coal-field, showing the pits and railways, faults, and other remarkable interruptions; a synopsis of the coal seams; a working plan of a colliery, showing the system of working and ventilation; a collection of the fossil plants of the coal formation; and specimens of household, caking, manufacturing, and cannel coal. There were also specimens of the strata and rocks of the coal formation, and of the carboniferous limestone formation; specimens of coke, safety lamps; sectional drawings, showing the engines, pumps, &c.; also a model, showing the method of drawing coals from the mine, and screening the same at the surface; models showing the mode of ventilating coal-mines, and of an underground ventilating furnace. Mr. Watson exhibited one of the old steel mills used for producing light before the introduction of the safety lamp. This consists of a disc of steel mounted in a frame upon a horizontal axis: on turning the disc rapidly round, by means of a handle, the edge is made to strike against a piece of flint, thereby producing a succession of sparks, which are not sufficient to ignite the fire-damp. The light thus afforded is very feeble, and an attendant is required to keep it in action. In the ventilation of coal-mines, as already explained, the direction of the ventilating current is regulated, and the fire-damp prevented from extending, by stopping up certain *ways* with doors, which are attended by boys, whose duty it is to close them after the passage of a wagon; but the boys are apt to fall asleep, and leave the doors open. A simple contrivance, invented by Mr. Robert Mills, was illustrated by a model of an apparatus for opening and closing doors in mines by a reversion of levers, one opening and the other closing the door, on each side of the door; and whether worked by the carriage drawn by a horse, or pushed by a man or boy, the action is the same. In the colliery where this apparatus has been used, there has not been an explosion of gas for twenty-two years; and we were informed that the coal-owners of the north were so much struck with its utility, that they determined at once to adopt it. This is one of the numerous instances of the value of the great industrial congress: men from different parts of the world compare their several inventions, and thus mutually benefit each other and the public at large.

The productive coal area of the Newcastle coal-field has been calculated at 360,000 acres in Durham, and nearly 150,000 in Northumberland. Of this quantity, about 67,000 acres have been worked. The average thickness of the seams is about 12 feet: an acre contains 4,840 square yards, and each cubic yard of coal weighs about a ton. This coal-field has therefore contained upwards of 10,000,000,000 tons of coal, of which about one-eighth has been consumed. The present annual consumption is estimated at nearly 16,000,000 tons. The coal is all bituminous, and the qualities vary with the proportion of bitumen. There are three qualities; viz. the common *caking* kinds, coarser kinds called *splint*, and *cannel* coal. The average quantity of gas from the caking coals is about 8,000 cubic feet per ton, the weight of coke being from 10 to 12 cwt. Cannel coal yields from 10,000 to 12,000 cubic feet of gas per ton.

The thick coal of Staffordshire was illustrated by large specimens outside the building. One was a fine column, showing the different working seams as they exist in vertical section. There was also a complete section of the seam in the form of a block, 18 feet in circumference, and weighing 5 tons: it was the largest specimen that could be brought out of the mine up a 7-feet circular shaft. The rope and chains used in lifting it were also exhibited, and it was stated that only the ordinary machinery employed in the colliery was used. There was also a specimen of the thick coal, 9 feet 6 in. high, 21 feet 10 in. in circumference, and weighing 13 tons. It was conveyed 70 yards underground to the bottom of the shaft, and raised from a depth of 165 yards by the steam-engine in ordinary use.

The Barnsley coal, from the great central coal-field of South Yorkshire, Nottingham, and Derbyshire, a district extending from Leeds to Nottingham, and including 650,000 acres of coal-field, was illustrated. The qualities, which are bituminous, or household coal, steam-coal, cannel, and anthracite, vary in different localities. There was exhibited a complete section of the thick bed, showing the different portions applicable for steam-engines, manufacturing purposes, and domestic uses. In this field is also found that curious variety called *iridescent* or *peacock* coal, from the circumstance of its fracture reflecting a variety of colours. A column of this coal, from the old Silkstone colliery, was exhibited. It has not been decided whether the iridescent appearance arises from a thin film of foreign matter deposited on its surface, or from the mechanical condition of the surface itself, as in mother-of-pearl.

The great coal-field of South Wales was fairly represented. This valuable field presents nearly 1,000 square miles of productive coal area; it comprehends *anthracite* or stone-coal, and *bituminous* coal, and also an intermediate semi-bituminous variety, termed *steam-coal*. The line which separates the bituminous from the anthracitic coal, is nearly coincident with the Neath Valley, the anthracite portion extending to the west. The anthracite has not been in use many years; but it is now of great value for certain special purposes, among which, we may refer to the skilful and ingenious application of it in the roasting of copper ore [see COPPER, page 429]. It sometimes contains as much as 92 per cent. of carbon; 1 lb. of it will evaporate 10 lbs. 8½ oz. of water, while the best bituminous coal evaporates not more than 8 lbs. A noble column of steam-coal, weighing 16 tons, was also exhibited from the main coal of the Flintshire coal-field. [See FUEL.]

Cannel coal, from the Wigan coal-field, was exhibited, together with various vases and ornaments turned out of the same. This coal is of fine quality, and takes a high polish. The Wigan coal-field is a portion of that known as the Lancashire and Cheshire, or Manchester, great coal-field, the productive coal area of which is nearly 400,000 acres: it is divided into three principal portions, of which the middle one includes the thick coal-seams. The principal varieties of coal are a good caking coal, and a valuable bed of cannel.

The coal region of the south of Scotland was represented by a block of coal raised from the lowest stratum of the Victoria coal-pit, in Renfrewshire. There were also specimens of the alum ore, or schist, which lies immediately above the coal, and of the limestone, which lies immediately above the alum ore. Alum ore, in process of decomposition, and alum made from the ore, were also shown. [See ALUM.] This colliery, which is 173 fathoms deep, is in the great coal region of the South of Scotland, and is supposed to comprise more than a million acres of productive coal. In the Renfrewshire coal-field there are 10 seams of coal separated by thin bands of clay. The Lanarkshire coal-field also contributed specimens of its coal, iron-stone, and limestone, the three grand materials required in the production of iron, and associated together in vast abundance in this country.

Ireland sent a specimen of anthracite from the coal-fields of Kilkenny, a district which includes a series of basins or troughs, separated by carboniferous limestone. The strata are sandstones and shales, with fire-clay and several valuable beds of stone coal, of fair quality.

SUMMARY OF COAL PRODUCE OF THE UNITED KINGDOM FOR 1859.

	Tons.
Durham and Northumberland	16,001,125
Cumberland	1,041,890
Yorkshire	8,357,100
Derbyshire, Nottinghamshire, and Leicestershire	5,050,000
Warwickshire	355,750
Staffordshire	6,125,000

Lancashire	10,650,000
Cheshire	700,500
Shropshire	765,770
Gloucestershire, Somersetshire, and Devonshire	1,250,000
North Wales	1,652,000
South Wales	9,600,250
Scotland	10,300,000
Ireland	120,300
Total	71,979,765

COBALT occurs in nature in combination with arsenic, as *arsenical cobalt;* or with sulphur and arsenic, as *grey cobalt* ore; but it is also contaminated with iron, nickel, and other metals. The ores remained without value until about the middle of the sixteenth century, when they were first applied for imparting a blue colour to glass; but the nature of the mineral was not known until it was examined by Brandt, in 1733, who obtained from it a new metal, which he named cobalt.[1] Cobalt is also found in most meteoric stones. It is not used in the metallic state: indeed, the processes for its reduction are difficult and complicated, and are carried on only in the laboratory on a small scale. The metal is brittle, of a reddish grey colour, of the density 8.5, somewhat more fusible than iron, and it is attracted by the magnet.

There are two oxides of cobalt: the protoxide, $Co\,O$, and the sesqui- or peroxide, $Co_2\,O_3$. The former possesses the property of colouring glass blue, even when present in very minute quantity. No other colouring-matter is so permanent or so intense: hence, a glass formed of this oxide, under the name of *smalt*, is of great importance in the arts, it being the blue colouring matter used for ornamenting porcelain and earthenware, for staining glass, for painting on enamel, for tinting writing-paper, and for a variety of other purposes. The interesting processes concerned in the manufacture of smalt will be described presently. The protoxide, which is prepared by igniting the carbonate, is a powder of an ash-grey colour. When precipitated by an alkali from its solution in acids, it forms a hydrate, of a fine blue colour. The salts of this oxide have a reddish colour in solution. This oxide combines with alkalies and earths: dissolved in fused potash, it gives a blue colour to the compound; and when magnesia, or a body containing it, is touched with a drop of nitrate of cobalt, and dried and ignited, a feeble but characteristic rose tint is obtained. A beautiful blue pigment, known as *cobalt blue*, almost equal for purity of tint to ultramarine, is obtained by mixing a solution of a salt of pure cobalt with a solution of pure alum, precipitating the liquid by an alkaline carbonate, washing the precipitate with care, drying and igniting it strongly. A fine green, known as *Rinmann's green*, is similarly prepared, by combining oxide of cobalt with oxide of zinc, or 1 part sulphate of cobalt and 2 or 3 parts sulphate of zinc, dissolving, and precipitating by means of carbonate of soda; and the precipitate, when washed and calcined, acquires a green colour.

Chloride of cobalt is obtained by dissolving the oxide in muriatic acid. The solution is of a pink red, but when highly concentrated, it is of an intense blue. The chloride, the nitrate, and the sulphate of cobalt form what are called *sympathetic inks*. Thus, if characters be written on paper with the chloride, they remain colourless and invisible, or nearly so; but by warming the paper near the fire, the writing becomes of a beautiful blue colour. As the paper cools, moisture is absorbed, and the colour disappears, but may be reproduced by heat. The addition of a salt of nickel gives a green instead of a blue colour. Thus, in painting what are called *magic landscapes*, the sky is painted with pure chloride, and the trees and grass with a solution containing nickel. Nitrate of cobalt forms a red sympathetic ink.

Phosphate of cobalt is an insoluble precipitate, of a deep violet colour. 2 parts of this and 1 part of arseniate of cobalt, carefully mixed with 16 parts of alum and strongly ignited for a considerable time, produce a beautiful blue pigment called *Thenard's blue.* It is said to have all the characters of ultramarine: it has lately been substituted for smalt in the manufacture of paper.

When protoxide of cobalt is calcined with a borax-glass, it absorbs oxygen, and a black mass is obtained, which, mixed with oxide of manganese, forms a fine black, which is used in enamel-painting.

Smalt is principally manufactured in Germany and Norway. In the year 1840, the imports into Great Britain amounted to 118,638lbs., of which 97,751lbs. were from Norway, and the remainder from Germany and Holland. In 1842, the imports amounted to 145,470lbs. By the new tariff an import duty of 10*s.* per cwt. is levied on smalt: this has greatly promoted the sale of a rival colour, artificial ultramarine, which is prepared at a very cheap rate at Cologne and other towns on the Rhine, and being admitted free of duty it has for the most part superseded smalt for paper-hangings, and all those cases in which it is not used as an enamel colour. The following is a very brief outline[2] of the manufacture of smalt as carried on in Saxony.

The success of this manufacture depends in great measure upon the purity of the materials employed, and on the exact proportions in which they are combined. The ore of cobalt is first picked, to separate stony matters, then sifted, stamped, and washed, by which means it is reduced to a coarse powder, and the earthy matters are separated. The ore is then roasted, for the purpose of separating arsenic and sulphur: this is done in a reverberatory furnace, to which is attached a tube of great length, or a series of chambers for the purpose of condensing the fumes

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(1) According to Beckmann, ("History of Inventions," vol. i.) cobalt was dug up in great quantity in the mines on the borders of Saxony and Bohemia, about the end of the fifteenth century. It was thrown aside as a useless mineral, entailing fruitless labour on the miners, and injuring their health by the arsenical particles contained in it. The word *cobalt* is supposed to have been derived from *cobalus*, the name of a spirit which was reputed to haunt mines, destroying the labours of the miners, or giving them much unnecessary trouble. "The miners, perhaps, gave this name to the mineral out of joke, because it thwarted them as much as the supposed spirit, by exciting false hopes, and rendering their labour often fruitless. It was once customary to introduce into the church service a prayer for the protection of miners and their works against *kobolts* and spirits."

(2) Abridged from a paper read by the Editor before the Society of Arts, London. 5th March, 1851.

of arsenic [see ARSENIC]. As an additional precaution, in order to prevent the escape of these fumes as much as possible, the ores in some places, as at Querbach, are roasted only in winter, when, the country being covered with snow, the arsenical vapours cannot injure vegetation, and the low temperature facilitates condensation. The dressed ore (schlich) is wetted, and spread over the sole of the furnace in a layer 5 or 6 inches deep: the heat is then cautiously raised for 6 hours, during which abundant white vapours of water, arsenious and sulphurous acids are evolved: the heat is then increased, and continued for 16, 18, or, at most, 21 hours. The ore is moved about with a rake whenever the vapours cease to be disengaged. Every part of the charge is thus brought under the action of the flame and of the strong draught of air which accompanies it; the object being to expel as much of the arsenic and sulphur as possible, and to convert the cobalt into an oxide. When the vapour ceases to be formed, and the schlich is at a red heat, the operation is terminated, the roasted ore is withdrawn, and the furnace allowed to cool before a fresh charge is put in, otherwise the new ore would become pasty. The quantity of arsenic deposited in the chambers amounts to as much as from 25 to 30 per cent. of good ore: the roasted ore now contains oxide of cobalt, oxide of iron, a small quantity of the arseniate of this metal, together with oxide of lead, titanium, &c.

The sand, or cobaltiferous quartz, which is obtained during the stamping of the ore, is also roasted with some of the dressed ore: it is then sifted, and the pieces which remain in the sieve are pounded, and again roasted. The best ore, when dressed, loses in roasting as much as 50 per cent.; the common ore 40; and the cobaltiferous quartz only 6.

The ores of cobalt, dressed and roasted as above described, are known in commerce under the name of *zaffre* or *saflor*.[1] This substance communicates a magnificent blue colour to glass, and is the chief ingredient in the manufacture of smalt. The other materials,—the silica and the potash,—are also prepared with great care. The silica is obtained by roasting lumps of quartz for 24 or from that to 36 hours; the effect of which is to destroy the cohesion of the quartzose particles. The quartz loses all its transparency, and becomes of a dull white, or yellowish if it contain oxide of iron; it can easily be crushed between the fingers; and the stamping-engine, well supplied with water, readily reduces it to a fine sand. This sand is calcined in a reverberatory furnace, sifted, and then, by repeated washings and decantations, the impurities, consisting of small portions of oxide of iron, lime, and oxide of manganese, are got rid of. The pure sand is finally calcined, to expel moisture, sifted, and stored in boxes for use. The potash is also purified with great care: it is then calcined, and preserved from moisture.

By the combination, by means of heat, of these materials, viz. the roasted ore or zaffre, silica and potash, a *glass of cobalt* is formed, which being pounded, washed, and dried, constitutes *smalt*. But as the particular shade of blue depends upon the exact proportions of the above ingredients, it becomes a matter of considerable delicacy to adjust the relative proportions. The ores of cobalt vary considerably in quality, and the purity of the sand and of the potash may also slightly vary. Hence the manufacturer, before commencing operations on a large scale, makes sundry trials on a small one, and he is able to judge from the results of his small crucibles how to apportion the materials in his glass furnace. Moreover, the manufacturer keeps various samples of smalt of different shades of blue, which serve him as a guide: these samples represent the shades which are known in commerce by certain numbers or letters, such as FC fine, MC middling, OC ordinary, FFFC finest, and so on with a large number of varieties both of zaffre, eschel, and smalt. M. Dumas gives the following recipe for making the shades marked OEG ordinary eschel, in powder or ground, and FOEG fine ditto:—

2½	cwt.	of ordinary roasted ore
2	,,	of the roasted mixture of ore and cobaltiferous quartz.
20	,,	sand
3½	,,	eschel or the slightly coloured glass, produced by washing the smalt.
10	,,	potash.
38 cwt		

The mixture for the smalt marked ME, MC, and FC, is:—

2	cwt.	of the best roasted ore
5	,,	sand
2	,,	eschel.
4	,,	potash
13 cwt.		

These ingredients are placed in regular layers in a wooden trough 2 feet deep; first a layer of sand, then a layer of schlich, and thirdly a layer of potash; the whole is then well incorporated by means of a shovel. This mixture is melted in pots, in a furnace similar to that used in the manufacture of GLASS. Each pot contains about ¾ cwt. of material, which is introduced by means of iron ladles, furnished with long handles. New pots are first filled with eschel, for the purpose of coating the interior with a vitreous glaze. In the course of about 8 hours the mixture fuses; the workman occasionally stirring it up with a red-hot iron in order to break up the crust which forms on the surface. The mixture becomes sufficiently fluid to effect a chemical combination of the materials only when the pots are at a white heat. The proper temperature is, in fact, that of an ordinary glass-furnace. If the potash be pure, the scum, which is known as *glass-gall* or *sandiver*, is not formed; but there is usually a portion of this substance to be skimmed off. If the cobalt ore contain nickel, as it usually does, a substance called *speiss* is formed, which, being heavier than the glass, subsides in the glass-pot. This speiss is an alloy of cobalt, nickel, iron, arsenic, bismuth, and sometimes silver. This must be separated from the blue glass, which is sometimes done by opening a hole provided for the purpose in the bottom of the glass-pot, and which during the melting is stopped up with clay and sand.

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[1] (1) In 1840, this country imported almost entirely from Germany 4,660 cwt. of zaffre. According to the new Customs' Duties, cobalt and zaffre can be imported free of duty; but a duty of 10s per cwt. is levied upon smalt.

Saxony produces annually about 8,000 cwt. of zaffre or smalt; Bohemia 4,000 cwt.; Prussia (Riesengebirge) 600 cwt.; Norway 4,000 cwt.

When the blue glass attaches itself to the man's rod, and can be drawn out in threads, it is ready for the next operation, which consists in ladling it out of the glass-pot and pouring it into a vessel full of water, which is kept cool by being constantly renewed. The man is careful not to pour any speiss with the blue glass, for this would injure its colour. All the pots are emptied before a fresh charge is put in, the temperature of the furnace being so greatly lowered by this operation, that it would be impossible but for this precaution to empty the last pot or two of glass.

The blue glass falling at a red heat into water, becomes granular and easy to pulverize. The preparation of this glass powder, however, involves a long series of laborious and curious operations, the science of which has not been very well explained. When the glass is taken out of the water it is drained and crushed in the dry state; then sifted to the size of ordinary sand; it is next ground in mills with granite runners on a granite bed, about 1½ to 2 cwt. of material being wetted and operated on for about 4 or 6 hours. The powder as it comes out of this mill is thrown into large vats full of water; in the course of a few minutes the heaviest portions of the glass, or those richest in cobalt, and consequently finest in colour, subside; this deposit is named *azure*. The water is then drawn off into a second series of vats, and allowed to stand for ¾ or from that to 1½ hour, according to the designed quality of the deposit. This deposit is named *Farbe*, the German word for *colour*. The water is again drawn off into reservoirs, where it is left for an indefinite length of time. Here it deposits various kinds of azure, known by the name of *blue sand*, or *Eschel*. The very short space of time required for the deposit of the azure, is subject to variation according to the season of the year. Less time is required in summer, when the water is warmer and less dense than in winter. A portion only of this first quality of azure, named *coarse blue* or *streublau*, is sent into the market in this state: the rest is again ground with a small portion of blue glass. But most of the azure and eschel thus obtained, is subjected to a final washing in tubs abundantly supplied with fresh pure water. The powder is stirred up with proper tools, and is then left to repose: all floating impurities, such as particles of glass-gall, are separated by means of a fine horse-hair sieve. The liquor is then decanted into another vessel, and a fresh portion of powder is subjected to the same treatment. In this way different varieties of smalt are obtained, either in the form of *farbe* or *eschel*.

The results of all these washings are, 1. a deeply coloured azure, 2. a powder *(farbe)* not so deeply coloured, 3. a sand *(eschel)* very little coloured. Dumas supposes that by these repeated washings, a portion of the alkali is removed from the glass, which is thereby brought more into the condition of a supersilicate. This action is most effective on the finer particles; less so on the coarse powder: and as it is essential to impart to the azure the property of retaining its colour in moist air, it has been found that a genuine azure can only be produced from glass of cobalt by repeated washings. This explains why alumina, lime, and bases which tend to make glass of cobalt resist the action of water, should be carefully excluded: arsenic and phosphoric acids tend on the contrary to assist the extraction of the potash, which being in combination with those acids, salts are formed which are more soluble than silicate of potash.

Glass of cobalt appears therefore to be a mixture of different compounds, which may be grouped into two principal varieties: viz. the less fusible silicates in which cobalt prevails, which resist the action of water, and the more fusible silicates in which potash prevails, which are more readily attacked by water. The former constitute *azure*, the latter by the action of water give up to that fluid a subsilicate of potash, and form a supersilicate of potash in a minutely divided state. This, doubtless, explains why it is that azure deepens in colour by the separation of a powder containing very little colour. In fact, the coarse blue powder which is first separated by the action of water is almost identical in composition with glass of cobalt: the azure contains more cobalt but less potash, and the eschel more silica and less potash and cobalt than glass of cobalt. The eschel also contains gelatinous silica, and the waters used in washing it carry away a subsilicate of potash.

The beauty of smalt depends in some degree upon the method of roasting the ore. If the ore is nickeliferous, the roasting must not be carried far; but the ore may be added in certain proportions to well-roasted ore, and the nickel is afterwards separated in the form of speiss.

Smalt may therefore be said to contain silica, potash, cobalt, and arseniate of potash. The last is small and variable in quantity, and its amount depends upon the roasting. It is not an essential ingredient in smalt, but it greatly influences the beauty of the colour. Indeed, according to Dumas, the beauty of smalt depends greatly upon the presence or absence of certain substances in small quantity, such as from 4 to 5 per cent. of arsenic and arsenious acids, 6 to 9 per cent. of phosphoric acid; the colour is also greatly heightened by very small portions of zinc, tin, antimony, and nitre. On the other hand, the tint is weakened or injured by the presence of nickel, lead, or iron beyond 10 per cent., bismuth, borax, soda, alkaline earths, alum, felspar, fluor spar, sulphur, &c.

The following is an example of the mode of manufacturing the variety known by the mark OC (common azure).

The smalt having been reduced to powder, is mixed with water and left for 45 minutes: the water is then drawn off, and there remains at the bottom of the vessel a coarse azure blue, which is a blue glass in a less minutely divided state than that which remains suspended in the water. The water thus drawn off is left for a much longer time, in order to separate the coloured particles which form azure, from the nearly colourless particles which form eschel. At the end of 36 hours the water appears feebly coloured. It is drawn off into a vessel and left until it is perfectly colourless. It is then thrown away, and the deposit is eschel, which is dried and added to the mixture used in charging the glass-pots.

The azure blue adheres strongly to the vessel in which it is deposited: it is broken up with mallets, and reduced to powder by being passed between cylinders: it is then washed many times in different waters. About 3 cwt. of the colour are put into the vat, the water is then added and the whole stirred up with a wooden tool until the azure is completely suspended: the floating impurities are removed by means of a fine sieve, and the whole is then left for 22 or 24 hours. At the end of this time, the water, still a little coloured by means of eschel, is passed into another vat: the second deposit is taken out and broken up, well mixed with water and then left for 18 or 20 hours; the water is then decanted. The operation is repeated a third time, and the deposit is allowed 16 or 17 hours to form. The water being decanted, the washing is finished. All the shades of azure are treated in the same manner, the only difference being in the time allowed for the deposit, which varies according to the required shade.

All these precipitates are removed from the vats, and being collected are dried in a hot room, or in a room in which the air freely circulates. They dry into compact masses, which are broken up by means of cylinders, or by mills. The produce is then passed through sieves of various degrees of fineness enclosed in boxes, or a bolting-cloth is used. The powder is then dried in a room heated from 100° to 115° by a flue passing under it. The powder is placed in layers 2 or 3 inches thick on raised platforms to dry by the hot air of the room, and is moved about from time to time by means of a rake. 27 cwt. of azure can be dried by this means at one time. When sufficiently dry, the azure is again ground and sifted. It is then compared with the marked and numbered standards already referred to, and its number being assigned to it, it is packed up in small quarter-of-a-hundredweight casks slightly moistened on the inside, and the proper mark and number is marked on the outside.

It is calculated in this long series of minute operations that every 100 quintals of glass of cobalt produce about 60 or 70 quintals of azure blue or coarse blue.

Smalt is used in the manufacture of porcelain, pottery, stained glass, encaustic tiles, fresco-painting, &c.: the paper-maker also employs it to cover the yellow tint of his paper. Berzelius remarks that the silica contained in writing-paper blued by it blunts the nibs of pens. Smalt was formerly used in the manufacture of bank-note paper, and the ash produced by the periodical combustion of notes at the Bank forms a blue vitreous slag, which may often be met with in collections of minerals. Blue-tinted writing-paper leaves a fine blue ash when burnt, and often exhales the peculiar odour of arsenious acid from the presence of this substance in smalt. There is some difficulty in keeping the smalt uniformly suspended in the pulp, and hence the lower side of the sheet is generally bluer than the upper. This defect has led to the use of artificial ultramarine for blueing writing-paper. Cheap ultramarine is also used as a substitute for smalt and Thenard's blue, in producing the brilliant and durable blues of paper-hangings. The celebrated blues of Sèvres porcelain are produced from cobalt dissolved in acids and precipitated.

COCCULUS INDICUS, the fruit or seed of a tree, *Anamirta cocculus*, belonging to the order MENISPERMACEÆ, growing upon the coasts of Malabar, Ceylon, &c. This seed contains the venomous principle *picrotoxine*, and in the pericarp is the poisonous alkaloid *menispermine*. The seed is sometimes thrown into waters for the purpose of intoxicating or killing the fish, and it is said also to be used by some brewers as a substitute for hops, and by publicans for increasing the intoxicating properties of ale or beer.

COCCUS, see GALL INSECT.

COCHINEAL is an important dyeing material composed of the dried bodies of cochineal insects, natives of Mexico, Georgia, South Carolina, and some of the West India islands. The cochineal insect is small, and was long mistaken by Europeans for some kind of grain or seed. It feeds on a kind of cactus (*Cactus cochinellifer*), with small, deep, red flowers. The juice of this plant is supposed to give the colour to the cochineal. The insects are detached from the plants by a blunt knife, put into bags, and dipped in boiling water to kill them. They are then dried in the sun, and again packed in bags (each bag containing about 200 lbs.) for exportation. The appearance of the dye as thus received varies greatly according to circumstances. If the insects are of the fine sort, and have been killed in the manner just stated, they are of a reddish or purplish brown colour; if they have been killed by the heat of an oven, a white powder, with which they are covered when alive, is not removed, and the whole mass of insects appears of an ashen grey. If the insects have died on the trees, they will be of a blackish hue. Cochineal insects are carefully cultivated in plantations of their favourite cactus, but an inferior sort is very common in the woods, feeding on a thorny cactus there. This is called *wild cochineal*, but even when introduced into the plantations it remains inferior, and is sold at a lower price. Wild cochineal yields one-third less colouring matter than fine cochineal. The species of cochineal called *granilla* or dust is supposed to be principally made up of this inferior sort. The demand for the best cochineal during the war was so great that this, together with obstacles in the way of its importation, raised the price from 12*s.* or 13*s.* to 36*s.* and 39*s.* per lb. Since 1814 the price has sunk gradually to from 4*s.* to 6*s.* per lb. And although lac dye has lately been partially employed for dyeing scarlet, yet the consumption of cochineal is on the increase. In 1840 the quantity entered for home consumption was 510,554 lbs.; in 1841 it amounted to 1,120,655 lbs. The duties on cochineal were reduced in 1842 to 1*s*. per cwt. They had previously been 6*d*. per lb. on foreign, and 2*d*. per lb. on colonial cochineal. In 1846 the duty was entirely repealed. In 1860 the imports amounted to 22,486 cwt. See CARMINE.

COCK, see CASTING.

COCO-NUT TREE (*Cocos nucifera*). The great variety of uses to which this tree is applied by the natives of the countries where it grows, and the commercial value of some of its products, render it peculiarly interesting in an industrial point of view. This tree is found in the tropical parts of the world, chiefly in the vicinity of the sea, growing within reach of salt water, and taking root upon reefs and sand banks as soon as they emerge from the ocean. Its principal range is said to be between the equator and the 25th parallel of latitude, and in the equinoctial zone; it will grow at various elevations under about 2,900 feet above the sea level. This tree is sometimes found to occupy extensive tracts to the exclusion of all other trees. The whole Brazilian coast from the river San Francisco to the bar of Mamanguape, a distance of 280 miles, is with a few exceptions thus occupied.

The coco-nut palm rises like a slender column to a height of from 60 to 90 feet. Its stem is soft and fibrous, and it is marked on the outside by rings produced by the fall of its leaves, two of which are said to drop off every year. About 11 or 12 leaves, each from 12 to 14 feet long, form a tuft at the top. The flowers proceed from within a large pointed spathe, which opens on the under side. In wet seasons the tree blossoms every five or six weeks, so that there are often fresh flowers and ripe nuts on the tree at the same time. There are from 5 to 15 nuts in a bunch, and in good soils a tree may produce from 8 to 12 bunches every year.

The *roots* of this tree are sometimes masticated by the natives instead of the areca-nut. The Brazilians make baskets of the small roots. The hard woody *shell*, or crust of the *trunk*, is employed by the natives in making drums, and in the construction of their huts, &c. Towards the base of the trunk, the wood is remarkably hard, and admits of a high polish: a transverse section well polished and varnished, rivals the agate in lustre. The reticulated substance at the base of the *leaf* is in some places formed into a cradle or couch. In Ceylon, it is used for straining the sweet juice which is extracted from the flowering spathe of this tree. It is also manufactured into a durable sackcloth called *gunny*, but according to some, gunny-cloth is made of hemp. The unexpanded *leaves*, or terminal *leaf-bud*, is occasionally eaten by Europeans, as well as by natives. When boiled it is tender, and forms a good substitute for cabbage. The natives sometimes preserve it in vinegar, and eat it as a pickle. The tree, however, dies when this part is removed. The natives thatch their houses with the *leaves*, for which purpose, the central ligneous portion of the leaf is divided longitudinally; the leaflets of each half are then plaited or interwoven, and in this state they are employed to thatch cottages, to shelter young plants from the scorching rays of the sun, to construct fences, to form the ceiling of rooms, and to make baskets for carrying fruit, fish, &c. Sometimes baskets are made of palm-leaves, so close as to serve the purpose of buckets to draw water from deep wells. The immature leaves of the coco-nut tree have a fine yellow colour, and a beautiful texture resembling fine leather or satin: they are used for decking rooms, &c., and being translucent, they are used for making lanterns. In some islands, the leaflets are plaited into bonnets and hats. They are also used as a substitute for writing-paper, the pen being an iron stile. In this way letters are written, and are then neatly rolled up and sealed with gum-lac. In writing, the leaf is held flat in the left hand, and the letters are scratched upon the surface with the iron point. Instead of moving the hand with which they write towards the right, they move the leaf in a contrary direction, by means of the thumb of the left hand. To render the characters more legible, the engraved lines are frequently filled by besmearing the leaf with fresh cow-dung, and then tinging this substance black; or the lines are rubbed over with coco-nut oil, or a mixture of oil and charcoal powder. Baskets for catching fish, shrimps, &c. are made of the ligneous ribs of the leaflet; these ribs are also formed into pins, tooth-picks, &c., and made into a bundle, they form excellent brooms. With the exception of the framework, every part of a house, walls and roof, is formed of coco-nut leaves; such a house is capable of resisting all kinds of weather for a year or more. A coco-nut leaf fixed along the stem of a fruit-tree, serves as an alarum; as the leaf rustles very much when touched, a thief is cautious of ascending the trunk, lest he should alarm the inmates of the neighbouring huts. In travelling by night, coco-nut leaves are used as torches; by tying the leaflets close to the centre rib of a leaf, the ignition is prevented from being too rapid. Such torches are in constant use to scare away wild beasts, particularly elephants, from cultivated fields. The coco-nut tree, especially the leaves, when burned, affords a large quantity of potash, which is used as a substitute for soap. Boats are rowed with the centre rib of the leaf. The end of this part of the leaf being well bruised, makes an excellent brush, which is used for a variety of purposes. The *spathes*, or fibrous covering of the blossoms, are inflammable, and are often employed as torches. By soaking in water, this part of the tree forms a coarse cordage used for securing the thatch of houses. The *flower* and *fruit* of this tree afford many useful products. By a peculiar manipulation, the flower yields a rich saccharine juice convertible into arrack or sugar. For this purpose, a man named a "toddy-drawer" ascends the tree, cuts off the point of the spadix, and passes a ligature firmly round the stump. It is then beaten with a stick, which is supposed to determine the sap to the wounded part. This process is repeated for several days, a small portion of the end of the spadix being cut off each day. The juice soon begins to flow from the cut surface of the flower, and is carefully collected in an earthenware vessel suspended from the spathe. A thin portion of the flower and spathe is sliced off daily, and the end of the stump is bound with a ligature. A good healthy blossom will give from 2 to 4 pints English of sweet juice or *suri* daily, and some flowers will continue to yield juice for 4 or 5 weeks. There are frequently 2 spathes on one tree yielding suri at the same time, which by exposure to the air immediately begins to ferment, and forms the intoxicating liquor, *toddy*. By distillation, this juice yields about one-eighth part of arrack, of the same strength as good brandy. The seamen belonging to the Royal Navy in the Indian Seas, are furnished with it instead of rum. By allowing the juice to pass into the acetous fermentation, an excellent vinegar is obtained, in which a great variety of vegetables are pickled. Suri is the yeast commonly used by the bakers in Ceylon.

In order to obtain sugar (*jagery*) from suri instead of spirit, great care must be taken to prevent fermentation. The earthenware pot in which it falls is emptied twice or thrice in the course of 24 hours, and is well cleaned and dried each time; a small quantity of lime is then thrown into it: the juice is filtered through the reticulated substance at the base of the leaf, and then slowly boiled in an earthenware vessel until it becomes light coloured and viscid. While still warm and semifluid, it is poured into sections of coco-nut shells, where it soon becomes solid. A gallon of juice yields about a pound of sugar. Jagery contains both the crystallizable portion of the juice, and a quantity of molasses or liquid sugar; but they are separated by a subsequent operation. This coarse sugar is usually made into small loaves of the shape of a hemispherical vase from the form of the vessel in which it cools. It has a deep chocolate colour, and when broken presents many clear particles of sugar. In the Malay language, jagery is called *goola* or *goora itan*, black sugar or black sweet.[1] Jagery is sold at the rate of about 2*d*. per pound.

Intimately mixed with lime, jagery forms an excellent cement, which resists moisture, and endures great solar heat. It also takes a very fine polish. Walls are prepared for receiving this covering by wetting them with a strong infusion of the husk of unripe cocos, and the same kind of fluid is used for mixing and tempering the materials. In Madras, and other parts of India, the flat tops of the houses are covered with this cement. It is also employed to form the floors of rooms, to cover columns, &c. Floors of this kind are sometimes stained, and made to resemble the finest marble.

When the flower has not been injured the tree bears *nuts*, which are converted to many useful purposes; young coco-nuts are much used by the natives as an article of diet. During the unripe state of the fruit the shell is lined with a pulpy substance, while the centre is filled with an aqueous fluid. This fluid is at first slightly astringent, and sub-acid; as the fruit ripens it becomes sweetish and not unlike the colour and consistence of the whey of milk. When drunk before the sun has far advanced it is much cooler than the atmosphere, and is then a pleasant beverage. Natives, particularly when travelling, generally furnish themselves with a few unripe nuts, the water of which they drink, and eat the pulpy portion or kernel. A few meals of this kind will support a labouring man from morning till night, without any other article of diet. The Malays train monkeys to fetch coco-nuts from the trees as they are wanted, and in this occupation they are expert and docile. The native inhabitants of the coasts of some of the islands in the equinoctial zone, procuring their food with so much ease, are little sensible to the ordinary motives which impel mankind to labour. They are more palmivorous than granivorous, and the man who possesses a garden with 12 coco-trees and 2 jack-trees has no call to make any exertion.

The *husk* or fibrous pericarp of the nut is employed to polish furniture and to scour the floors of rooms, &c. Birds that construct pendulous nests commonly employ this substance. Its chief use, however, is in the manufacture of *coir*, and for this purpose the nut ought not to be completely ripe. To remove the husk, an iron spike or sharp piece of hard wood is fixed in the ground; the nut is then forced upon the point, which passes through the fibres and separates the rind from the shell. In this way one man can clear 1,000 nuts daily. Coir is prepared by soaking the rind in water for several months, and then beating it upon a stone with a piece of heavy wood. On the coast of America, when a running stream of water is not near, the coir manufacturers dig holes in the sand below high water-mark, and bury the rind before beating it. It is subsequently rubbed with the hand until the interstitial substance is completely separated from the fibrous portion of the husk. The rind of 10 nuts furnishes about 6 lbs. weight of coir. The next operation is to twist the fibres into yarns, which are manufactured into cordage of all sizes. Coir is remarkably buoyant, and well suited for ropes of large diameter. Sea water is said to be beneficial rather than hurtful to it, and the cordage, when properly prepared, is pliable, smooth, strong, and elastic; it is well adapted for running rigging, but, on account of its contractibility, it is not so well suited for standing rigging. Dr. Roxburgh found the comparative strength of hemp-rope and coir-rope when large to be as 108 to 87, and when small as 65 to 60. The natives sew the planks of their boats together with coir yarns. Coir is much used in India instead of hair, to stuff mattrasses, cushions, saddles, &c. It is also employed to make brooms and brushes for the purpose of white-washing houses.

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(1) The Sanscrit word *goor* signifies *sweet*, the superlative of this word *soogoor*, sweetest, is supposed by some to be the origin of the word sugar.

The *kernel* of the ripe nut resembles an almond, and is the *bread* of many of the natives. By a little pressure it yields a white fluid, resembling milk, which is used as a substitute for it in tea, &c. Another substitute for milk is obtained by rasping the kernel and mixing the scrapings with some of the liquid contained in the nut, and then straining. In Barbadoes puddings are made of coco-nuts, and when pressed with honey and sugar the kernel is used to make preserves. The ripe nut is also used in Ceylon to furnish an oleaginous fluid required to prepare curry. But the chief product of the kernel is its *oil*, which is extracted either by decoction or expression. In the former process the fresh kernel is finely rasped, the raspings are then washed with water, which becomes milky, and by decoction yields a limpid oil. If the emulsion be exposed for a night, it separates spontaneously into an oily and a watery portion, and the oily portion is purified by a very short boiling. To separate the oil, the operator, who is generally a female, lays the palm of her left hand flat upon the surface of the fluid; a portion of oil adheres to the hand, which is brushed off into a vessel by the right hand. The oil made in this manner is nearly as colourless as water, and when newly prepared has no offensive odour, but if exposed to the air a few days it becomes offensive. 10 nuts yield on an average about a quart of oil, but according to another authority 32 nuts yielded only 3 lbs. of pure oil. When the oil is prepared on a large scale, compression is resorted to. After clearing the nut of the husk, the kernel is exposed, which is effected by breaking the shell with a crooked knife, an operation which is generally performed at one stroke. The watery part of the kernel is dissipated by exposing it to the sun for a few days, during which period it acquires a considerable degree of rancidity. The oil is extracted by grinding the kernel in a very clumsy mill, worked by bullocks; but at Colombo steam-power is used for the purpose. The substance which remains after the oil has been extracted serves well to feed pigs, poultry, &c.

Large quantities of nuts are brought to this country from the West Indies. The captains of ships use them instead of wedges of timber for filling up the vacant spaces between the casks and other packages which compose their cargoes. On this account the freight of the nuts adds little to their original cost.

In Ceylon the oil is used as a lamp oil. The natives burn it in a section of the shell with cotton wicks. Torches are prepared in Siam by drying elephant's dung, soaking it in coco-nut oil, and then covering the mass with long, dry leaves, tied at short distances with shreds of bamboo. The natives also use the oil for anointing their bodies. It is used also instead of olive oil in the preparation of ointments, plasters, &c., and in making mercurial ointment it is said to divide, or *kill*, the mercury better than any other vegetable oil. Melted with resin it forms a substance used for paying the seams of boats and ships, and also for protecting the corks of wine and beer bottles from the depredations of white ants.

The *shells* of coco-nuts are manufactured into beads for rosaries. They are also used as drinking vessels and for various other domestic purposes. Occasionally they are polished by the natives, who cut figures in relief upon them. When thus ornamented they are sometimes employed by the English as sugar basins; and in South America the ladies drink tea out of highly-ornamented coco-nut tea-cups, sucking it through a long silver tube. Ladles are formed of a part of the nut, with a long wooden handle attached. The natives of some of the oriental islands use the shells as measures both for dry and fluid substances. Their capacity is known by the number of cowries they will contain. Hence there are cocos of 500 or 1,000 cowries, and so on. The shells are also used as fuel by the goldsmiths; and when converted into charcoal they are mixed with lime, and employed to colour the walls of houses. Lastly, from various parts of the coco-nut tree the natives prepare many remedies for a variety of diseases.[1]

COFFEE is the seed contained in a berry, the produce of a tree, *Coffea Arabica*, of the order of *Cinchonaceæ*. This tree grows to the height of from 8 to 12 feet, and has long slender branches bending downwards, and furnished with evergreen opposite leaves. The blossoms are white: the fruit is a red berry with a pale, insipid, somewhat glutinous pulp inclosing two hard oval seeds, each about the size of an ordinary pea. One side of the seed is convex, the other is flat, with a straight furrow inscribed through its longest dimension. While growing, the flat sides of the seeds are towards each other, and they are covered by a cartilaginous membrane called the *parchment*. Coffee requires a warm climate, a new soil, and a gentle slope to prevent water from lodging at the roots. The trees are raised from seed in nurseries, and afterwards transplanted out. They begin to bear at two years old, and in their

Fig. 596. THE COFFEE PLANT. (*a*, section across the ripe fruit.)

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(1) Our information has been chiefly derived from a paper inserted in the fifth volume of the 'Memoirs of the Wernerian Natural History Society," entitled "Contribution to a Natural and Economical History of the Coco-nut Tree," by Mr. Henry Marshall, Surgeon to the Forces, &c.

third year are in full bearing. The period of flowering does not last more than two days. In one night the blossoms expand so profusely that the trees appear as if covered with snow. The seeds are known to be ripe when the berries have a dark red colour. In Arabia the planters spread cloths under the trees, and on shaking them the ripe berries drop readily. In the West Indies the berries are picked by the negroes. "In curing coffee it is sometimes usual to expose the berries to the sun's rays in layers, 5 or 6 inches deep, on a platform. The pulp ferments in a few days, and having thus thrown off a strong acidulous moisture, dries gradually during about three weeks. The husks are afterwards separated from the seeds in a mill. Other planters remove the pulp from the seeds as soon as the berries are gathered. The pulping-mill used for this purpose consists of a horizontal fluted roller, turned by a crank, and acting against a movable breast-board, so placed as to prevent the passage of whole berries between itself and the roller. The pulp is then separated from the seeds by washing them, and the latter are spread out in the sun to dry them. It is then necessary to remove the membranous skin or parchment, which is effected by means of heavy rollers running in a trough wherein the seeds are put. This mill is worked by cattle. The seeds are afterwards winnowed to separate the chaff, and if any among them appear to have escaped the action of the roller, they are again passed through the mill."[1]

There are several varieties of the coffee-tree, the result of differences in soil and climate. Arabia is its reputed native country; but the virtues of the berry are said to have been first known in Persia. Its use was for some time checked by the Syrian Government on account of its supposed intoxicating qualities; but it is reported to have been publicly sold at Constantinople in 1554. The first coffee-house in London was opened in George Yard, Lombard Street, by one Pasqua, a Greek, who was brought to London in 1652 by a Turkey merchant named Edwards. About 1699 the quantity of coffee consumed in the United Kingdom was 100 tons a-year, of which 70 were used in England. It was sold in druggists' shops at about 2*s.* 8*d.* per pound.

Coffee is supposed to owe its refreshing character to a peculiar chemical principle, *Caffeine*, which appears to be identical with that obtained from Tea (*Theine*). This substance belongs to the class of azotized basic bodies, and from its presence in two substances so dissimilar as tea and coffee, one or both of which is in such general use all over the world, it may be supposed to be of importance to our animal economy. Liebig has shown that the composition of caffeine ($C_8H_5N_2O_2$) is closely related to that of various animal products, and that there is reason to believe that it may assist in the secretion of bile. A pound of coffee yields by sublimation on an average about 15 grains of caffeine. It may also be obtained from an infusion of raw coffee when certain impurities have been removed by subacetate of lead, and the excess of lead by sulphuretted hydrogen. It forms white silky crystals, which are sparingly soluble in cold water, and in alcohol easily by the addition of heat. It has a mild bitter taste.

The following analysis of coffee berries has been published by Payen:—

Cellulose or woody fibre	34·000
Water	12·000
Fat or oily matter	13·000
Glucose and dextrine or sugar and gum	15·500
Legumine and caseine	10·000
Chlorogenate of potash and caffeine	5·000
Azotized substance	3·000
Free caffeine	0·800
Essential oil	0·003
Mineral Substances	6·697
	100·000

The peculiarly refreshing and stimulating properties of coffee are developed in the roasting. According to Cadet, coffee roasted to a pale brown colour loses 12.3 per cent.; to a chestnut brown, 18.5 per cent., and to a black, 23.7 per cent. Schrader found in roasted coffee—

Extractive matter soluble in water and alcohol, closely resembling that of raw coffee, but browner and deliquescent	12·5
Brown gum	10·4
Extractive soluble in water but insoluble in alcohol	5·7
Oil and resin	2·0
Insoluble burned woody fibre	69·0

A portion of tannine appears to be formed during roasting. "Schrader endeavoured to ascertain the particular principle to which the flavour and aroma of roasted coffee are due, by exposing each of the proximate principles of unroasted coffee separately to heat; but he found that no one of them yielded any peculiar flavour, and that the ligneous residue, when roasted, acquired as much of the characteristic flavour as when the other principles were retained; so that the flavour of the roasted coffee must be ascribed to the joint effect of heat upon all the constituents. The caffeine seems to play a very passive part as far as flavour is concerned, and a considerable proportion of it remains unchanged after roasting, whilst another part of it is merely volatilized.[2]

The usual method of roasting coffee is very simple. A large iron drum containing the coffee is made to revolve over an open fire, as in Fig. 597. The drum is covered with a case or hood, which confines the heat; but when the man wishes to see how the roasting is going on, he throws back this hood, and by turning a handle at the side, lifts the drum completely out of the fire upon two projecting arms which support the axis. Then by opening a sliding door in the drum, the coffee can be examined. At Messrs. Barry's establishment (to which we are indebted for much information, as well as for the pictorial sketches which illustrate this notice, and the previous notices of CHICORY and CHOCOLATE) they roast during the winter season about 3 tons of coffee every day. They calculate that the loss in roasting amounts to rather more than one-fifth, but less than one-fourth

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(1) Dr. Lankaster. "Vegetable Substances used for the Food of Man."

(2) Brande. "Manual of Chemistry," p. 1178.

of the weight of the green coffee. The vapour of water which is first expelled escapes by an aperture in the axis of the drum. When the roasting is completed the berries are turned out into *coolers*, Fig. 598, which are large shallow troughs with wire gauze bottoms suspended between upright posts, and balanced in the centre. These troughs are attached to a bar at the side, which passes up to the projecting arm of a horizontal bar, which is moved through a portion of a circle by the reciprocating action of another bar shown in front of the figure. This causes the troughs to tilt backwards and forwards, by which means the berries are kept in constant motion, and are freely exposed to the air until they are cold, and any husk or dust is separated, and falls out through the meshes of the wire. This cooling seems to be necessary, for roasted coffee, especially in large quantities, is liable to heat, and to such a degree when ground as to take fire. Some mysterious accidents from fire have been referred to this cause, such as the burning of a frigate in the port of Cronstadt, when no fire had been in her for several days before. M. Georgi roasted a quantity of coffee until brown, and without grinding it tied it up in linen and set it by. No particular result was observed, but when two pounds of roasted coffee were ground to powder and tied up in a similar manner, it took fire and continued to burn until it was reduced to ashes. Similar trials were made with roasted barley and rice, with the same results.

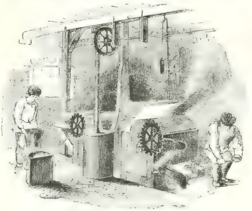

Fig. 597. ROASTING COFFEE.

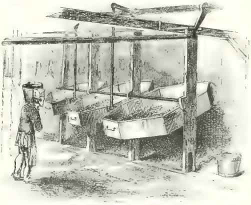

Fig. 598. COFFEE COOLERS.

When coffee is roasted, a quantity of water is given off in the form of steam, so that the berries are for a time exposed, at a high temperature, to an atmosphere of watery vapour. Judging from the injurious effects upon many plants used in medicine, of drying them in a confined space where their watery particles cannot freely escape, it seems probable that this confined vapour must be injurious to the coffee. If coffee be heated in a glass mattrass and stirred so as to prevent burning, it soon acquires a very unpleasant odour from the water being confined; but if a sample of the same coffee be roasted on a flat surface exposed to the air, there is no such result. By continuing the heat after the greater part of the water has been expelled, the coffee begins to grow brown, and as the process is continued, it is obvious that the interior of each kernel must be roasted to a less degree than the exterior portion. This under-roasting of the interior produces a raw flavour. If, however, the roasting be continued until the inside is properly done, then the outside will be roasted too much; the consequence of which will be a burnt and bitter flavour. We therefore cordially agree with the suggestion made by Mr. Donovan,[1] that the green coffee be dried in a large shallow iron pan over a very gentle fire, constantly stirring until the colour become yellow: this will dispel the greater part of the water. The berries should then be pounded into coarse fragments, each kernel into 4 or 5 parts for example, and transferred to a close roasting apparatus and roasted to the proper degree. The dealers, to prevent what they think too much loss of weight, commonly underroast: 16 ounces on an average are reduced to only 14: the berries when ground furnish a brownish powder with a tinge of orange, and the infusion wants the enlivening qualities for which coffee is valued. The greatest number of advantages in roasting, are obtained by reducing 15 ounces to 12 by a very gentle heat. A greater loss than this (which is ⅕th) produces a bitter flavour, and less than this a raw one. When ground, or even when whole, the colour should be a bright chocolate, and the liquid coffee of a brilliant brown with a tinge of orange.

Those who have leisure to roast their own coffee, may first dry it in a thin layer in a frying-pan over a slow fire, frequently stirring; when all the moisture is expelled, let the roasting be done in a common glass oil-flask: this will roast as much as a quarter of a pound at a time, but it is best to roast only as much as is wanted at one time. The flask will bear the heat of a naked fire without injury, but it should be kept constantly turning round. The common sheet-iron roaster is not only injurious from its confining the vapour, but also from its conducting the heat too quickly. The glass being a bad conductor is free from this latter defect. The common sheet-iron roaster would be greatly improved, if, as Mr. Donovan

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(1) Domestic Economy. Vol. II in Lardner's "Cabinet Cyclopædia."

suggests, it were made double; that is, one cylinder within another, half-an-inch space being left between them. The roaster should never be filled more than one-third, for by roasting the bulk is nearly doubled.

Mr. Donovan proved that grocer's coffee is not sufficiently roasted, by the following experiment. 4 oz. of grocer's ground coffee were boiled in successive pints of water, until the last had scarcely taste or colour: the grounds were then dried before the fire and roasted in an oil flask, and being boiled in a pint of water the decoction had a strong taste of coffee, although it was too bitter.

The question whether coffee should be boiled or infused may be thus answered:—By infusion in boiling water, the aroma is extracted and a portion of the bitter; by long boiling the whole of the bitter is extracted and all the aroma dissipated. Now an excellent method of making good coffee is to put a liberal supply (such as 2½ ounces to the imperial quart measure of water) of freshly roasted and finely ground coffee into the coffee-pot; pour over it *cold* water in quantity rather more than half the required quantity of liquid coffee, place this on the fire, and the moment it boils remove it: it should be allowed to subside for a few seconds, and then be poured off as clear as it will run. The remaining half of the water at a boiling heat is next to be poured on the grounds; the vessel is to be placed on the fire and kept boiling for three minutes: this will extract the bitterness. After subsiding for a few moments, the clear part is to be poured off and mixed with the former liquor. The mixed liquor will be quite hot enough, and will contain all the desirable qualities of coffee in perfection.

After the above directions it is not necessary to notice the numerous forms of coffee-pot which are brought before the public with so much pretension. The *percolator*, introduced by Count Rumford, has been repeated under a great variety of forms: the objections to it are, that it does not exhaust the ground coffee of its virtues, and that the liquor requires so long a time to percolate, that it is too much cooled before it passes through.

The use of a small quantity of carbonate of soda is said to improve coffee. Professor Pleischl states, that the well-water of Prague is admitted by all to be better adapted to the making of coffee than the river-water of that place. On examining the well-water he found it to contain a small portion of carbonate of soda. He therefore recommends the addition of 43 grains of the pure carbonate to every pound of roasted coffee: this, he says, will improve the flavour, and increase its therapeutic effects by neutralising the acid contained in the infusion.

Those who use fining materials will find a piece of clean eel or sole skin answer the purpose, or still better, white of egg prepared by pouring the white of a number of eggs into a large flat dish, and exposing this for 12 or 14 hours to heat in front of the fire. As the water evaporates, the albumen forms into a yellow, transparent, hard, shining brittle mass, which scales off at the least touch, a test that it is properly done. This may be kept in a bottle for a great length of time, and when wanted, a small piece of about the weight of a sixpence is sufficient to clear 3 ounces of coffee. It must be thrown into that half of the water which is to be boiled, and when the two portions are afterwards mixed, the coffee will become quite transparent in a minute or two.

The addition of a single tea-spoonful of port wine improves the flavour of coffee. It is common on the continent to use ardent spirits with coffee; this however is not coffee drinking, but dram drinking.

The duty on coffee, by the new tariff, was fixed at 6*d*. per lb. from foreign countries, and 4*d*. per lb. from British possessions. This reduction of duty has led to a reduction in the prices of coffee of from 15 to 22 per cent.; and yet, while the increased consumption of sugar, and of every other taxed article, has during the same period furnished conclusive evidence of the soundness of the doctrine, that every judicious reduction of taxes must eventually more than compensate the Exchequer for the temporary sacrifice of revenue, coffee alone has presented the anomalous and exceptional instance of a commodity whose consumption has not only not increased, but has actually decreased as its price has diminished. In 1846, there were entered for home consumption 36,793,061 lbs. of coffee, in 1849 only 34,431,071 lbs., and in 1860, after a lapse of eleven years, only 35,674,381 lbs. The revenue from coffee has of course also fallen off proportionally, the receipts having been 643,218*l*. in 1849, and only 442,120*l*. in 1858. This falling off cannot be attributed to a diminished demand for the article called or misnamed coffee, but to an extensive system of adulteration. For some time, chicory was the chief article used in adulterating coffee; but it is stated that "there are other roots which, when kiln-dried, curl up, and assume the same appearance as chicory root; the parsnip, the white-carrot, the beet-root, the radish, and any such. Many of the growers of chicory have hit upon the plan of adulterating it, by the addition of these roots, to the extent of 25 and frequently 50 per cent." Nor are torrefied vegetables the only fraudulent substitutes for coffee, nor the most deleterious. It is stated by some of the London memorialists on this subject, that the substances most largely used are roasted acorns, peas, beans, red-pottery earth, sand, mahogany saw-dust, colouring-matter, and finings. [See APPENDIX.]

COFFER-DAM, see BRIDGE.

COG, see WHEEL.

COHESION, (Lat. *cohærere*, to hold together,) the force by which particles of matter form collective masses, requiring the application of force to separate them. The common notion of matter in the solid and liquid states is, that the particles of which they are composed are in absolute contact. This view, however, is quite inconsistent with the well-known property of matter, to expand by heat, and to contract by cold: it is also inconsistent with other facts, such as the peculiar manner in which liquids mingle; water and sulphuric acid, or water and alcohol, for example, when mingled together, produce an apparent penetrability of matter; a pint of water and a pint of sulphuric acid producing considerably less than two pints of the mixture. We may also notice the intimate manner in which liquids penetrate into the interior of solids. The particles of the stone filter allow water to pass through, which would not be the case if those particles were contiguous or in contact. Hence the particles must be separated by interstitial spaces, by some force which tends to remove them further apart; while another force acting in an opposite direction, tends to unite them or to bring them closer together. This latter force is called *cohesion*, and the former is supposed to be *heat*.

The nature of this attractive force, or cohesion, is not known. There are similar forces in nature, such, for example, as are exhibited by vitreous and resinous substances, which acquire by simple friction the property of attracting light bodies; so also, the lodestone attracts iron, and is attracted by it. The celestial bodies gravitate towards each other with a force which is directly as their mass, and inversely as the squares of their distances. The forms of these bodies, as well as the form of our earth, are such as masses of matter would naturally take when impressed with a rotatory movement, supposing their particles in the first instance to be free to move according to the above law. The attraction is less apparent, but not less real, when exerted between the particles of solid and those of liquid bodies, into which they are plunged. Examples of this are given under CAPILLARY ATTRACTION. The wonderful changes which are brought about in chemistry, result from the operation of forces acting only at very small distances, modified however by the nature of the particles, or by their form, or by both together. The infinite number of particles which react on each other, and the variety of circumstances which modify their properties, render this subject very complex.

The great antagonist of cohesion is *heat*. A bar of metal exposed to its influence expands, that is, the particles are separated from each other to greater distances; by continuing the application of heat, the force of cohesion may be so far weakened, that the particles will glide over each other and form a liquid; that this is a forced state, is evident from the fact that by withdrawing a considerable portion of the heat, the particles approach closer together, until the solid state is formed; a further reduction of temperature brings them still closer together, and causes the solid to contract, or in other words, the attractive force of cohesion prevails over the repulsive force of heat.

But this separation of particles can be carried much further in some bodies than in others: in water, for example, a range of temperature from 32° to 212°, which would have very little effect on a bar of metal, is sufficient to render water solid at the lower temperature, liquid at intermediate temperatures, and vaporiform at the higher temperature. Now, the water in the state of vapour occupies a space 1,600 times greater than in the liquid state: nevertheless, it has not changed its nature: its particles are separated to so great a distance from each other as to be invisible; but we have only to lower the temperature, and they will reunite into drops and return to the state of liquid. On continuing to lower the temperature, we arrive at a point when water not only ceases to contract by cold, but apparently, in opposition to the universal law, expands. This point, at which water is in its state of greatest condensation by cold, is 39.45° Fahr.: below this, any reduction of temperature down to 32° produces expansion, during which the particles probably arrange themselves into that state or condition necessary to the freezing or crystallization of water. At 32° the fluid water becomes solid ice, and a still further and sudden expansion takes place the moment the water becomes solid.

But the state of vapour is not the last term of this remarkable series of changes. If we pass vapour of alcohol through a red-hot porcelain tube, the constituents of the alcohol separate: solid carbon is deposited, and the other constituents are evolved in the aëriform state, in the form of permanent gases, which cannot be reduced to the liquid form by any amount of cold which we can command. Now, in this case, as well as in the case of water in the vaporiform state, the cohesion of the particles is not only entirely overcome; not only is their mutual attraction destroyed; but a force of an entirely opposite nature is generated; the particles repel each other with an intensity depending on the temperature. It is this repulsive force which leads to the bursting of steam-boilers, and which gives elasticity to air-cushions. Only there is this difference, that the vapour of water and other liquids can by simple reduction of temperature be condensed again into liquids; whereas gaseous bodies, such as oxygen, hydrogen, and nitrogen, have never been condensed into liquids by the application of intense cold and pressure. Hence these bodies are called *permanently elastic*,—a term which must not be taken too strictly, because Dr. Faraday, many years ago, condensed to the liquid state eight gases, which had previously been regarded as permanently elastic; and more recently he has not only liquefied, but solidified several others. All the gases thus condensed, except chlorine, are compounds. [See CARBONIC ACID.]

These facts also tend to throw some ambiguity into the term, "the natural state of bodies;" for the solid state is as natural to water as the liquid, provided the temperature be sufficiently low; and the vaporiform state is as natural as the solid and the liquid, provided the temperature be sufficiently high.

By hammering, or by other means of compression, some solid bodies can be made more *dense*, or, in other words, a larger amount of matter, or a greater number of particles, can be crowded into a given space. But there is, doubtless, a limit to this,—a point at which the cohesive force ceases and the repulsive force begins. It has also been suggested by Mossotti that there might be an intermediate distance, at which the particles neither attract nor repel one another, but remain balanced in that stable equilibrium which they appear to maintain in solid and liquid substances. As the particles are not in actual contact, Mossotti supposes each particle to be surrounded by an atmosphere of electric fluid; that the atoms of this fluid repel one another; that the molecules of matter repel one another, but with less intensity; and that there is a mutual attraction between the particles of matter and the atoms of the fluid. He also assumes those forces which are known to exist, to vary inversely as squares of the distance. From the adjustment of these three forces, the following results have been obtained:(1)—" When the material molecules of a body are inappreciably near to one another, they mutually repel each other with a force which diminishes rapidly as the infinitely small distance between the material molecules augments, and at last vanishes. When the molecules are still further apart, the force becomes attractive. At that particular point where the change takes place, the forces of repulsion and attraction balance each other, so that the molecules of a body are neither disposed to approach nor recede, but remain in equilibrio. If we try to press them nearer, the repulsive force resists the attempt; and if we endeavour to break the body, so as to tear the particles asunder, the attractive force predominates, and keeps them together. This is what constitutes the *cohesive force*, or *force of aggregation*, by which the molecules of all substances are united. The limits of the distance at which the negative action becomes positive, vary according to the temperature and nature of the molecules, and determine whether the body which they form be solid, liquid, or aëriform. Beyond this neutral point, the attractive force increases as the distance between the molecules augments, till it attains a maximum; when the particles are more apart, it diminishes; and as soon as they are separated by finite or sensible distances, it varies directly as their mass, and inversely as the squares of the distance, which is precisely the law of universal gravitation. In aëriform fluids, the particles of matter are more remote from each other than in liquids and solids; but the pressure may be so great as to reduce an aëriform fluid to a liquid, and a liquid to a solid, as in Faraday's experiments.

" If the particles approach sufficiently near to produce equilibrium between the attractive and repulsive forces, but not near enough to admit of any influence from their form, perfect mobility will exist among them, resulting from the similarity of their attractions, and they will offer great resistance when compressed; properties which characterise liquids, in which the repulsive principle is greater than in the gases. When the distance between the particles is still less, solids are formed; but the nature of their structure will vary, because at such small distances the power of the mutual attraction of the particles will depend upon their form, and will be modified by the sides they present to one another during their aggregation. Besides these three conditions of matter, there is an infinite variety of others, corresponding to the various limits at which the two contending forces are balanced, which may be observed in the fusion of metals, and other substances, passing from hardness to toughness, viscidity, and through all the other stages to perfect fluidity, and even to vapour.

" The effort required to break a substance is a measure of the cohesive force exerted by its particles, which is as variable as the intensity of the repulsive principle. In stone, iron, steel, and all brittle and hard bodies, the cohesion of the particles is powerful, but of small extent. In elastic substances, on the contrary, its action is weak, but more extensive. Since all bodies expand by heat, the cohesive force is weakened by an increase of temperature.

" Every particle of matter, whether it forms a constituent part of a solid, liquid, or aëriform fluid, is subject to the law of gravitation. The weight of the atmosphere, of gases and vapour, shows that they consist of gravitating particles. In liquids the cohesive force is not sufficiently powerful to resist the action of gravitation. Therefore, although their component particles still maintain their connexion, the liquid is scattered by their weight, unless when it is confined in a vessel, or has already descended to the lowest point possible, and assumed a level surface from the mobility of its particles and the influence of the gravitating force, as in the ocean, or a lake. Solids would also fall to pieces by the weight of their particles, if the force of cohesion were not powerful enough to resist the efforts of gravitation."

As examples of the force of cohesion we may mention the spherical form of rain-drops; the difficulty of detaching a plate of glass from the surface of water,—the cohesion of the upper layer of water in contact with the glass to the layer immediately beneath it resisting the separation; the perfect manner in which two freshly-cut surfaces of caoutchouc unite on being pressed together; the force, often amounting to a considerable weight, required to separate two smooth plates of brass or glass which have been firmly pressed together with a screw-like motion; these and similar examples of the force of cohesion are independent of atmospheric pressure: the plates of metal will cohere and support the same weight attached to the lower plate when the plates are suspended by the upper one in the exhausted receiver of an air-pump. A remarkable instance of cohesion is mentioned by M. Pouillet(2)—in plate-glass manufactories after the large plates have been finally polished, they are carefully wiped and set up on edge, resting against each other a little inclined, something like books on a book-shelf. In the course of time, and in this position, the surfaces cohere with a greater or less degree of force, and in some cases it was found impossible to separate the plates without breaking them; in this way three or four plates have become so intimately incorporated, that they could be worked as one plate, cut with the diamond, and ground into shape. Some specimens of glass which had thus grown together at the ordinary temperature, and by contact only, appeared as if they had been fused together: a very powerful mechanical force was required to make the uniting surfaces slide upon each other, and when they were apparently separated it was found that one surface had torn off large flakes of glass from the other.

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(1) This statement of these results has been abridged from Mrs. Somerville's "Connexion of the Physical Sciences."

(2) "Elémens de Physique Expérimentale." Liv. VI.

Some remarkable effects of the cohesion of liquids have been observed by M. F. Donny,[1] who found that a syphon gauge constructed by him with sulphuric acid, (perfectly free from air,) for the purpose of testing the air-pump vacuum, was useless; the acid remaining stationary, it being sustained by its adhesion to the tube, and the cohesion between its own particles. By means of these forces alone a column of sulphuric acid (free from air) was sustained 4 feet in height even in a perfect vacuum, although the apparatus was repeatedly agitated. With distilled water free from air the same phenomenon was observed; and by a series of comparative experiments the author is led to believe that cohesion alone can sustain a column of water over 33 feet. It is the absence of air alone that allows the particles of liquids to approach each other more closely and exercise more powerfully their cohesion, which, when air is present, interferes but slightly with the changes that liquids undergo; as, for instance, ebullition, which happens at about the temperature at which their vapours enter into equilibrium with the atmospheric pressure. But if water is as free from air as it is possible to make it, it can be heated to the temperature of 275° Fahr. without manifesting the slightest traces of ebullition, and that even in a vacuum. This remarkable fact has been proved by experiment, the instrument used for it being a kind of water hammer, so arranged that the vapour in the upper part could not be heated, and thereby exercise a pressure on the water,—which was heated to 275° without the cohesion of the particles giving way; showing that this force was superior to the pressure of 3 atmospheres, as under ordinary circumstances water, heated to 275°, furnishes a vapour equal to that pressure. But if the water heated to this high temperature be divided in any way, steam is instantly disengaged and with great violence, the temperature at the same time falling. In this way those sudden bursts of vapour which are often so annoying during the evaporation of liquids, are explained. At the first part of the ebullition, while air is present, the vapour is uniformly produced, the temperature of the water and of the vapour being the same; but the air once gone, the cohesion of the liquid interferes in the process; this induced the author to try what effect a current of air passing through the liquid would have in preventing these explosions, which resulted in perfect success. M. Donny thinks that the cause of certain explosions of boilers may be deduced from these facts, and proposes as a means of preventing them, to throw in at the bottom of the boiler a small stream of air. These experiments have an important bearing upon the point of ebullition of liquids.

Some remarkable experiments by Professor Henry, on the cohesion of water, are recorded in the Proceedings of the American Philosophical Society for April, 1844. The professor attempted to measure the cohesion of water by weighing the quantity of water which adhered to a soap-bubble just before it burst, and determining the thickness of the film by observing the colour it exhibited in comparison with Newton's scale of thin plates. Although experiments of this kind could only furnish approximate results, yet they showed that the molecular attraction of water for water, instead of being only about 53 grains to the square inch, according to the theory of capillarity of Young and Poisson, is really several hundred pounds, and is probably equal to that of the attraction of ice for ice. The cohesion of the particles of water was further illustrated by blowing a bubble at one extremity of a bent tube: on ceasing to blow, and removing the thumb from the other end of the tube, such was the contractile force of the bubble, that it sent a current of air out of the open end, sufficient in force to blow out a candle.

COINING. The first edition of this work contained an article under this head, in which were described the principal machines and processes connected with the coining of money at the Royal Mint. Since the date of that information a large number of improvements have been introduced leading to the necessity of a new article on the subject, which has been most kindly and liberally prepared for us by G. F. Ansell, Esq., the talented engineer of the Royal Mint. This article is so complete, and is illustrated with so large a number of figures, made expressly for the purpose, that we have no space for it here; but it will be found in the Appendix. We therefore cancel the Cyclopædia article, and substitute for it some interesting details from the "Report of the Select Committee on the Royal Mint," 1837; the "Report of the Commissioners Appointed to Inquire into the Constitution, Management, and Expense of the Royal Mint," 1849; also "Copy of Reports to show the Changes that have been made in the Management of the Royal Mint, and its Present State," 1852.

The business of coining, or the "Mystery of the Mint," is the art of putting stamps on pieces of metal made of a prescribed standard or quality, and otherwise so prepared as when of the same denomination to be uniform in appearance, and equal to each other in dimensions and weight. The first method employed in the preparation of money was that of pouring melted bullion into earthen moulds, previously impressed by the devices the coins were intended to bear. In such case the only apparatus required were a small cylindrical vessel used as a smelting furnace, a few crucibles and moulds, a pair of tongs, a cutting tool or file, and a set of weighing scales. This system was superseded by another in which the melted bullion was poured through a sieve (as in the modern method of casting leaden shot), and the resulting globules having been placed on a stone, and struck by a stamp with a hammer, were thus flattened, and the upper sides impressed with the device borne

(1) "Annales de Chimie," February, [illegible]; quoted in Silliman's American Journal of Science.

by the die. Such coins, bearing inscriptions on one side only, are now in circulation in Assam. It is stated that by a method combining the moulding process of the first system with the use of stamps in the second, the Greek coins, referred to as the finest in the world, were produced. Such a method, however, was inconvenient, tedious, and expensive. The next method was to cast cylindrical ingots of sizes corresponding with the diameters of the coins intended to be prepared, and as the pieces cut transversely from such ingots were already circular, they had only to be adjusted in weight by a file, and to be struck between dies by a hammer, to be complete for issue. One objection to this method was, that such bars are usually found porous, and often perforated by cavities, so as to occasion the waste and delay of repeated meltings. Mr. Ruding, in his "Annals of the Coinage of Great Britain," expresses the opinion that the last mode of coining was not usually adopted in the once numerous Mints of England, but that after the coins came to be stamped on both sides, the rude and inartificial expedient adopted was that of fixing one die firmly in a block of wood, and holding the other in the hand, when by striking the latter forcibly, and repeatedly, with a hammer on the piece of bullion placed between the dies, the impressions required were at length worked out. It appears that the money struck in the eighteenth year of Edward I. was made first by casting the bullion into long bars, which were cut with shears into square pieces of exact weight; then with the tongs and hammer they were forged into a round shape, after which they were blanched by *nealing* or boiling, and afterwards stamped with a hammer to make them perfect money. This method continued in use until 1561, when the "screw-fitted coining press," an invention first brought into use in the French Mint, was introduced, although the old method of coining by the hammer was not entirely superseded until 1662. The Report regards the first stage in the history of coining as commencing from the time when the art was first practised in this country, and extending to the latter date; while the second stage of its mechanical advancement was terminated, in 1788, by the great improvements introduced by Mr. Boulton, when he invented the machinery which was brought into use in the London Mint in 1810. It may be remarked that the heaviest operations were first performed by manual labour, afterwards by the power of water, or of horses, and ultimately by the agency of steam.

With respect to the persons entitled to coin money, it appears from early records that some of the Anglo-Saxon and early Anglo-Norman kings were accompanied in their progresses or wars by men whose business it was to convert bullion into coin. About the year 928 Athelstan enacted that no person should "mint," except in a town; and it appears that up to the thirteenth or fourteenth century the worker at each Mint was furnished with one or more pair of dies by an officer of state, called the *cuneator,* one of whose duties it was to see that the dies employed in the various Mints were of the same type, and that one of the dies of each pair was engraved with the name of the minter by whom they were to be used. The "monetarius, minter, or Mint master," to whom the dies were delivered, seems to have been the farmer of a Mint, or sole contractor, for conducting in it all the processes of coinage.[1]

It appears that from the time at which Mints were first established in Britain down to the year 1544, the contract for the meltings, as well as for all the other operations of coinage, was held by the master, and that from this period to 1571, the whole of these processes were farmed by the Crown; that from this date to 1626 they were again conducted under contract by the master; that from this year to 1670 the meltings only were farmed by the Crown, which then, as has since been customary, formed contracts with other parties for the moneying operations, and that in 1670 the melting contract reverted to the master, who down to the year 1799 either employed his deputy, or first clerk, in superintending the meltings, or sub-farmed them on contract.

So long as coining was a manual operation requiring expertness and practical skill in forging the pieces round, and in hammering them between the dies, such processes were well adapted for objects of contract; for in this, as in other cases, it is better for a manufacturer to employ expert workmen on piece-work or contract, than to pay them or less skilful artificers, without reference to the quantity of work effected, by daily or monthly wages Such a system, however, was less applicable when the cutting out the blanks, and striking the coins by machinery was introduced in 1662 by Blondeau. The system of contracts became still more inapplicable when processes calling for the exercise of individual expertness were entirely superseded by the agency of steam. The introduction of Blondeau's improvements was, however, long effectually resisted by the moneyers or sub-contractors for the coinage, who used the "hammer-and-tongs" method practised previous to the year 1662. "Their predecessors had, with equal pertinacity, but with better success, contended against other attempts of a similar description; nor, if the representations of their descendants could have prevailed, would the Royal Mint have been provided in 1810 with steam-powered machinery similar to that brought into use at Soho in the year 1788. By substituting at the 'battering' or 'laminating' mills the power of steam for the costly labour of horses, and in some Mints for that of 700 or 800 men, and by similarly affording means of correctly forming the blanks, and

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(1) The above methods of minting do not seem to have prevented the debasement of the coinage. Mr. Ruding quotes authorities for the statement that Henry I., in 1125, sent orders from Normandy that all the moneyers in England should be punished by having the right hand struck off, because the money was so corrupted that it would not pass in any market, "and these parties having been summoned to Winchester by Roger, Bishop of Salisbury, were taken apart singly, and underwent the dreadful infliction." It appears that ninety-four persons thus suffered. It is further stated that, in the reign of Henry II., the moneyers "were severely punished for adulterating the coin," and that, "besides other sufferings, they were bound two and two, and carried in carts to the King's Court."

of accurately striking the coins, the latter apparatus had rendered of no avail such admirable skill as without the loss of fingers is known to have enabled a moneyer to read a newspaper whilst feeding a coining press, or such expert applications of physical force as, in conjunction with musically timed labour, had sufficed to stamp the pieces; nor can it be disregarded that from the period at which these processes ceased to be manually conducted, the operative services of the parties by whom they had been performed could have been dispensed with."

It is stated that without reducing the average allowance of the moneyers below £937 per annum for weighing and watching the bullion, the introduction of the improved machinery was calculated to effect a saving of at least £210,000. In 1815 the master and worker of the Mint issued a report, in which it is stated, that "the deputy-master as the melter, and the company of moneyers (the principal heads of this branch), are paid chiefly by rates upon the manufacture of the coin in its various stages; and it is certain that these rates, whatever they might have been while the Mint was in the Tower, unaided by the modern improvements in mechanism, are, now that the machinery of the Mint is so perfect, by far too liberal, and that the public have a right to expect that the immense expense of erecting and fitting up the new Mint, shall at least be gradually defrayed by a saving in the Mint expenditure, as any private manufacturer would expect that the adoption of greater facilities and improvements in his manufactory must ultimately create a saving in the expenses of his manufacture." In this document the mode of payment was approved of, while the rates of payment were deemed excessive; indeed, it was shown that during thirty-two years, the moneyers and melters received no less than £757,104, more than half of which was admitted to be profit. The moneyers considered themselves as a corporation, and pleaded prescription as the foundation of their claim. They do not appear, however, to have had any grant or charter whatever, except such as is included in the general charter of the Mint. Hence they could not be considered as a separate corporation, although they claimed by prescription the right to execute all coinages within the Royal Mint, and refused to give any account of their large profits—so large, indeed, as to become burdensome to the country: thus, "in the great gold re-coinage in 1774, &c., the company of moneyers, being six in number, received for their share the vast sum of £104,423 5*s.* 3*d.*, and refused to give an account of the expenses they incurred, which prevented the master from ascertaining whether or not their actual profits were or were not unreasonable. In the last two years they have received from the Bank the sum of £29,000 for the manufacture of tokens, a sum much exceeding, we are told, that at which Mr. Boulton offered to contract for the same business, although the whole charge of building and machinery, which Mr. Boulton bears, is provided by the public for the moneyers, and the sum of at least £1,000 more was paid by government for labourers hired from Birmingham to assist them in their business."

The attempts to get at the accounts of the moneyers were met by those officers keeping such accounts as were only fully intelligible to themselves, or by occasionally burning those which they found it unnecessary or inconvenient to keep, or, thirdly, by keeping no accounts whatever of such things as they felt to be "strictly private."

While the moneyers continued to enjoy their profits, the "master and worker's" salary and contingent profits underwent several changes. In 1782 he received £5,652 13*s.* 1*d.*; from 1799 to 1831 his salary was £3,000; and since 1831 it has been £2,000: and there was this anomaly connected with the master's duties, that, while he contracted to perform all the operations of the coinage, the contract, or Mint indenture, also provided for the almost total transfer of the processes to other parties; so that two sets of people were paid for doing the same work,—"first, the master, by whom it is not done; secondly, the sub-contractors, by whom it is done." The principal operative duty of the master was the preparation of the dies, which were fitted up under his directions by the die engraver, and by parties acting under the orders of the clerk of the irons, who, assisted by workmen, claimed salaries and wages. In this way the dies became costly objects; for not only had the public to pay coinage rates to the moneyers, but also "to bear the charges incident to that essential but costly branch of mintage, the preparation of dies." When objections were made to the execution of the coins, the ready answer of the moneyers was that the dies were fitted up in an improper manner. They were either "too hard," causing them to shiver as glass would in the coining press, or they were "too soft," causing the neck of the lower die to squeeze down in the die-collar, and stop the press; or they were engraved too deep, so as not to be sufficiently filled by the piece of bullion placed between them, and which, therefore, in parts remained unstamped: or, if not too deeply engraved, they had some minute detail so artistically excavated, that no force of blow that could be given to the coining presses would bring up the impressions. In this way there was an antagonism kept up between the master and the "operative" portion of his establishment, and the moneyers.

Thus it will be seen that the Mint system was carried on by three classes of persons: first, by the operative branch of the master's establishment, including the clerk of the irons and superintendent of machinery, the die engravers, and the artificers who prepared the dies, collars, beds, punches, milling cheeks, press slides, and, generally, the minor parts of the machinery liable to wear; secondly, by the contractor for the meltings; and, thirdly, by the moneyers or contractors for the coinage. It is remarked that differences between these parties, or between them and the government officers, were invariably, through the nature of the agreements, decided against the public. It was stated that the contract system was necessary to secure the public from loss, but that the constant state of vigilance required for the purpose, was a source of inconvenience and expense; and that, should the business of the Mint change hands, by a system of open contracts serious risks would be incurred. As it was, the loss by waste and robbery in the coinage department was estimated at £700 on £1,000,000, which loss was borne by the moneyers.

The moneying departments were supplied by agreement with "clean bars." Any neglect in the process of melting—as by imperfect mixture of the bullion and alloy—would injuriously affect all the operations of the coinage; for, with the gold and copper alloy not properly blended, no care or attention in the processes of rolling or drawing would render blanks of perfectly equal dimensions of the same weight, since one of the pieces would contain too large a proportion of copper, and thus prove too light, and another too much gold, and be too heavy; and in either case, such pieces being beyond "the remedy" for weight, must be returned to the crucible.

Considering these and other practical difficulties, it is admitted that on the whole the average coinage work of the Mint was well performed, however costly. Credit for all that was well done was claimed by the contractors, but the report remarks that the final correctness of the coins, as to fineness, depended on the Queen's Assay Master; that their correct mechanical execution depended on the die and collar fitters, and on the care of the workmen who managed the machinery; that the beauty of design and relief of the coins depended on the artistical skill of the die engraver; and that their accuracy as to weight rested chiefly with the workmen employed by the moneyers in the adjusting and subsequent operative department. The die-engraver of the Mint had been complimented both by Flaxman and Chantrey on the beauty of his work; which, it must be remembered, kept clear the distinction between coins and medals, for while the latter may be high and bold in relief, and have raised or other letters (qualities which will not interfere with their preservation in cabinets), coins intended for general circulation and exposed to constant wear should have their devices executed in low relief, so as to give the greatest possible beauty and effect, and to be in other respects, as in milling, in the proportions of the flat protecting edge, &c., best calculated to resist abrasion.

The necessity of accurate weighing by means of a weighing-machine, such as is in use in the Bank of England, is insisted on, since the final weight of the coins does not depend on the process of adjusting or weighing, but on the subsequent operations of pickling, drying (partly by shaking), and stamping. In pickling, some of the pieces most exposed to the acid are most acted on, and hence most reduced in weight by a solution of a part of their alloy. The weight of particular pieces may also be reduced by the abrasion incident to shaking, or still more by the friction arising from forcing them out of the die-collar by the recoil power of the stamping-press. The last-named source of loss is promoted by the fluting given to the die-collar, to enable it to form the serrated milling. This milling also greatly accelerates the wear of the coins, by converting each piece into something of the shape and quality of a circular saw, so that after long carriage the coins are found to have so acted on each other as to leave in any close package a measurable amount of bullion dust, and as the value of a grain of gold is nearly two pence, it was calculated that the additional rapidity of wear occasioned by serrated milling led to a loss of £8,000 per annum on the total amount of coin in circulation, without including the expense of more frequent recoinage. Such milling also facilitates the fraud of "drilling" and counterfeiting the coin, and giving a fictitious weight to light coin by the introduction of some extraneous substance into the fluting. Being thus expensive in various ways, and more troublesome to execute than a perfectly cylindrical and necessarily highly-polished edge, the latter ought to be preferred. It was further remarked that while sunk letters on the edge of a coin are objectionable as forming receptacles for dirt, and thereby affecting its weight, raised letters are as objectionable as serrated milling, and facilitate the process of drilling, especially in large coins, by which, as is often done in India, two-thirds of the contents are removed, and a base metal substituted, for which purpose any one of the letters, easily replaced by another letter formed on the end of a circular wire of bullion, affords the means of concealing the spot where the drill was introduced.

The Report of 1849 concludes that the then existing Mint system was one leading to much useless expense, and not reconcileable with efficiency. Assuming the expedience of terminating existing contracts, a plan was given for having the work effected wholly by a salaried establishment, the great object being to keep clear of "such contract arrangements as practically end in monopolies, and are at variance with subordination, efficiency, and economy." The new plan was so constituted as to give to the public, at the earliest possible period, the benefit of every improvement realised in the branches of science relating to coinage.

At the time when this plan was under contemplation, Mr. Shiel, the Master of the Mint, accepted the appointment of British Minister at Florence, and was succeeded by Sir John Herschel. In February, 1851, notice was given to the moneyers to terminate the contract, and pensions were granted to them for life. A list of officers and artisans in the various departments, together with their salaries, was made out, and the business of the Mint was carried on under new arrangements. In addition to the resident officers a change was made in the assaying department. The standards of fineness, both of gold and silver coin, as indicated in the Mint indenture, were made by comparison with certain trial plates. The progress of the art of assaying showed this method to be at variance with the end proposed, and that strict conformity to the trial plates entailed deviations from the exact standard—for gold, to the extent of 12 grains in the pound troy, in defect; for silver, to that of $1\frac{1}{2}$ pennyweights in the pound in excess of the legal standard. This discordance was pointed out by Mr. Bingley, the King's Assayer, in 1830, and new trial plates were constructed by which the true standard, in the case of silver, was exactly restored. In the gold plate, however, after allowing for a certain technical correction due to an ascertained loss of gold in the then usual mode of assaying, an outstanding error in defect, to the extent of 3 grains in the pound troy, still remained, which it was not thought advisable at the time to correct, since the sudden removal of the whole error might act as a premium on the melting of the coin. The improvement, however, was gradually made, and the legal standard secured as nearly as the delicate operations of melting and assaying would permit.

Under the new Mint arrangements, Mr. Field became Resident Assayer, Mr. Sterry, Assistant Assayer, while the duties of scientific assayers to the Mint, not resident within its precincts, were undertaken by Professor Miller, of King's College, London, Professor Graham, of University College, London, and Mr. T. Johnson, of Gresham Street—a commercial assayer of very extensive practice.

A system of open contracts or tenders was devised for coining gold, silver, or copper money for the Master at the Royal Mint. The tenders, however, did not comply with the conditions, and the Master was required to prepare a plan for the execution of the coining by the agency of an establishment in the direct employment and pay of the government. Accordingly, a plan was drawn up, and approved by the Lords of the Treasury in July, 1851, in which the various officers are named, all persons employed in the Mint being considered as servants of the sovereign, under the immediate orders of the Master, and not allowed to carry on a private business of any description.

The Regulations for the Coinage of Gold Bullion at the Royal Mint are as follows:—

1. The Mint receives gold bullion for coinage on Tuesdays, Thursdays, and Saturdays, between twelve and two o'clock.

2. Any persons intending to deliver gold to the Mint for coinage must give one week's notice of their intention, by letter addressed to the Master of the Mint.

3. Before delivery the person delivering the bullion must make a written statement, in duplicate, on forms which will be supplied to him at the Mint, of the marks of each ingot, the report thereon of the assayer on whose assay he purchased it, and the name of that assayer.

4. At the time of delivery the ingots will be weighed through the Mint-office scale, and their weights entered in a column for the purpose, on each copy of the statement above mentioned.

5. The two senior officers of the Mint-office present will then sign the certificate at the end of each copy of this statement, and give one copy to the importer or deliverer of the bullion, and retain the other for the use of the Master of the Mint.

6. On the assays of the assayer to the Mint being completed a statement thereof will be sent to the importer of the bullion, together with the standard value at which the Master of the Mint is willing to receive it; and if not objected to within three days, it will be considered not to be objected to, and the bullion will be passed into work on that valuation.

7. If by the assay reports it appear that any of the ingots are brittle, or that they contain iridium, or that having been badly melted they cannot be properly assayed and valued, or that for any other cause they are unfit to be received for coinage, such ingots will be rejected; and if the standard value of the whole of the ingots be less than their gross weight, so that they cannot be brought to standard without the refinage of a portion of them, the Master of the Mint will only receive and coin without charge so many of the ingots delivered as will, when combined and melted together, produce standard gold without any process for refinage.

8. If the assayer of the Mint assign a lower value to any ingot than that assigned by the importer's assayer, and the importer object to the report of the Mint assayer, the metal shall be assayed by any two of the non-resident assayers of the Mint to whom the Master of the Mint shall choose to refer it, whose decision shall be final, and a receipt for the standard value of the bullion delivered shall then be given to the importer.

9. On the completion of the coin notice will be sent to the importer, and a time fixed for its delivery to him, when the same weight in gold coin as the standard weight at which the ingots were received will be delivered to him without any charge whatever.

We devote the remainder of our space to a few particulars respecting the practice of the Mint, illustrative of some of the foregoing remarks. And first, with respect to the "standard or trial-plates," there is no authentic account of them previous to the year 1660; but, it is probable, considering their use as a check to any deviation from correctness in the coin, and their value as objects to refer to, that they were introduced almost as early as money itself, or, at least, as early as the time when the various provincial Mints gave way to the one now existing in the capital. From the time of William the Conqueror, the quality of our coins, both gold and silver, had often changed, and this to suit the wishes and intentions of the sovereign or of the government for the time being. The variations embrace an extent of two ounces of fine metal in the pound for the gold coin, the greatest fineness being nearly purity, and the least degree of fineness not containing more than ten ounces of fine metal in the pound troy. Our present gold standard of eleven ounces or twenty-two carats fine gold, has existed from the time of James I. without alteration. The variations in the fineness of our silver coin are more considerable than in the case of gold. They descend from eleven ounces two pennyweights of fine metal as low as not more than four ounces of fine metal in the pound, as was the case in the latter part of the reign of Henry VIII. In the reign of Edward, it improved gradually to eleven ounces, remained nearly stationary in the time of Mary, but was finally fixed at eleven ounces two pennyweights in the time of Elizabeth, at which degree of purity it has been the desire of successive governments to preserve it; to which end trial-plates were prepared by the Goldsmiths' Company, as being next skilful to the persons engaged in the Mint, while, at the same time, the Goldsmiths were independent of the Mint. Supposing the two metals forming the alloy to be in a state of perfect purity and in correct proportions, the trial-plates may still be inaccurate if the mass be kept too long in fusion, or exposed to the oxidising influence of the air, the effect of which would be to make the aggregate too fine. Again, if there were not sufficient heat, and the melted mass not properly stirred, the plate might vary in different parts. According to the view of Mr. Bingley (whose statement has furnished us with the above particulars), a trial-plate should not be considered perfect until the synthesis and the analysis of it are in accordance. It was the custom, on the formation of a new trial-plate, whether of gold or silver (both having been usually formed at the same time), to divide it into three parts; one part was lodged at the Exchequer, another at the Goldsmiths' Hall, and the third at the Mint. These parts were of a size large enough to admit of their being used for many public trials of the monies coined, which trials were called "Trials of the Pyx," held at the Exchequer. The trial-plate by which our gold coin was compared at the trial in 1830, had been in existence a century and a half. A new plate was prepared with extraordinary care in 1829. It was made finer than the previous one by five grains troy in the pound, and although a little under the real standard, it was not under what would be called standard throughout the whole of Europe, the difference being merely to the extent of the small quantity of silver which nearly always accompanies gold, and is inseparable from it by ordinary means. It is the practice at all Mints to consider that standard which is really a little below it, and if we were to raise the value of our coins, our continental neighbours would probably melt them down.

There are established at the Mint what are called "Remedies," for fallibility of workmanship, both as regards the fineness and the weight of the coin. These are to protect those concerned in the several departments from censure or blame, for such slight deviation from the standard as in the rapidity of the coinage is sometimes unavoidable. The remedy on gold per pound was in early indentures one-eighth of a carat (1¼ dwt.); it was altered at various times, and continued long to be one-sixth of a carat or 40 grains. By the indenture of 1815 the remedy was lowered from one-sixth to one-sixteenth (15 grains), with the additional remedy of 22½ grains for quarter guineas and seven shilling pieces. Down to 1815 the remedy was always the same in amount, both for weight and fineness; but by the indenture of 1817, now in force, while the remedy in fineness, or at the assay, is one-sixteenth of a carat or 15 grains, the remedy in weight, or at the shear, is only 12 grains or one-twentieth of a carat.

The remedy on silver has also varied from time to time. With certain exceptions, however, the remedy was for a long time 2 dwt. by weight, both at the assay and shear, until 1815, when it was halved, and made 1 dwt. at assay and shear.

Originally, by the Mint agreement in 1279, the variation of the coinage below the standard, though within the remedy, was to be answered to the king, without any advantage to the Mint Master or any other person; but, as from the gradual depreciation in the value of money, and the increased expenses of labour, fuel, &c., the Mint Master's allowance often became insufficient, he seems occasionally to have been allowed to take part of the benefit of the remedy, until the sovereign agreed to raise his allowance to a sufficient sum, whereupon the whole of the variation was again to be answered to the king.

At an early period, the exclusive privilege of purchasing the precious metals was claimed by our sovereigns, in return for which they were ready to purchase all bullion that might be offered to them, at prices which it was a part of their prerogative to fix. Thus, up to 1464, the merchant received for his pound of standard bullion 30*s.* less by 3*d.* and 9*d.* (seignorage or royal duty and coinage expenses) or 29*s.*; but in that year Edward IV. ordained that the merchant should receive 33*s.* for his pound of standard silver, which became the current value of the pound of silver, 37*s.* 6*d.*, less 4*s.* 6*d.* for seignorage and coinage. Similarly in the indenture of 1543 it is recited that "the king hath advanced the valuation of fine gold, of the fineness of 24 carats, to 48*s.* per oz. In 1548, the valuation is advanced to £3 per oz. or £36 per lb. gold, and £3 8*s.* per lb. silver; while in the indenture of 1553, it is declared that there shall be paid "unto every person or persons that shall bring any bullion of silver into the said Mint, such price for the same, after the rate and fineness thereof as shall be appointed in the king's warrant on that behalf," &c.

The difference between minting and exchanging was, that the latter was instantaneous minting. If a merchant took a pound of standard bullion to the Mint or Change to be minted, he might, by waiting the time necessary for the process of minting, receive back a pound of standard coin, less only by the coinage expenses and the Mint seignorage; whereas, if he took the pound of standard bullion to the Mint to be changed, he might, without waiting at all, receive back a pound of standard coin, less not only by the coinage expenses and the Mint seignorage, but also by a further exchange seignorage. By the indenture of 1670, the seignorage was abolished in consideration of certain customs' duties granted in lieu thereof.

It appears that for several years the Bank of England has been the only importer of gold into the Mint, because private individuals would lose the interest of their bullion by the delay of coinage. The Bank would not formerly buy gold intended for coinage, except upon the assay of the king's assayer. The fractional difference between the purchase assay and the assay of the importer is a source of considerable profit to the Bank, no less than £50,000 having in this way been realised in fifteen years. In the purchase of bullion, there is a market price for silver and a fixed price for gold.

There are two departments in the bullion office of the Bank, one of which is connected with the Bank only, while the other is a deposit office for the accommodation of merchants.

Mr. Haggard, the chief officer of the bullion office, in his evidence given in 1848, states some particulars respecting the practice of the Bank in the melting of light coin into bars. £70,000 worth of gold coin, or about that, is made up into one hundred bags, to be melted into bars producing one hundred. A clerk from the Bank and a porter take them to Brown and Wingroves, private melters, and wait to see them melted; they are then brought back, counted, the assay is cut off, weighed, and put into the Bank books, and the assay is sent to Mr. Bingley, at the Mint, for his report, with the numbers of the bars on the papers; when they come back, the reports are entered into the book, and rated to bring them into standard. No bars are taken that have not Brown and Wingrove's stamp upon them, in order that the Bank may be satisfied that there is no baser metal in the bars. The Bank paid for melting gold bullion, and old coin 3*d.* per lb.; 15*s.* per cwt. troy for melting silver bullion or coin. For refining, the Bank pays 4*s.* per lb. for gold; for refining silver, an allowance of 5 grains of gold in the lb., with an advance of three-eighths on the market price. The merchants who import gold into the Bank, pay a higher price for melting—namely, bar silver and coin 15*s.* per cwt. troy, or the same price; gold coin 6*d.* per lb.; European bar gold from places where it has been already refined, 3*d.* per lb.; bar gold from Asia or America, 6*d.* per lb.; gold dust 1*s.* 6*d.*, because sublimate is used in refining it, in order to prevent its being brittle. The waste in melting fine gold is from 12 grains to 1 dwt. in a bar of 15 lbs. weight troy, the loss in melting sovereigns is from 1½ dwt. to 2 dwts. in 15 lbs. The loss in melting foreign gold coin is uncertain, from the uncertainty of its quality. The loss of weight in melting silver ingots, if fine silver and previously well melted, is ½ oz. to 1 oz. on 70 lbs., and the loss in melting dollars is from 1½ oz. to 2 oz. in 70 lbs. The loss of weight arises from the dirt, and also from the destruction of the alloy.

Mr. Haggard also stated that from the 2nd Jan., 1844, to the 15th April, 1847, light gold sovereigns were melted into 5,400 ingots, of which 4,731 were reported worse than the standard one-eighth of a grain; 669 were reported standard. The loss to the Bank from the report on the 4,731 was equal to £5,225.

The following statement concisely expresses the chief facts of the standard:—

GOLD.

Fine ...... $\frac{11}{12}$ Alloy ...... $\frac{1}{12}$

SILVER.

Fine ...... $\frac{37}{40}$ Alloy ...... $\frac{3}{40}$

GOLD.

934 ½ Sovereigns = 20 lbs. troy.
1 Sovereign = 123·274 grains.

SILVER.

66 Shillings = 1 lb. troy.
1 Shilling = 87·272 grains.

COPPER.

53,760 Pence = 1 ton.
1 Penny = ⅔ ounce.

THE REMEDY.

GOLD.

$\frac{1}{16}$ carat or 15 grains troy per lb. in fineness, 12 grains troy per lb. in weight, or ·257 grains on 1 sovereign.

SILVER.

1 dwt. = $\frac{1}{20}$ oz. per lb. troy.

COPPER.

$\frac{1}{40}$ per lb.

Some details respecting the new bronze coinage will be found in the Appendix.

In the year 1860 the number, weight, and value of the gold coins issued from the Mint were as follows:—

	Number of Pieces.	Weight in ozs.	Value.
Sovereigns . .	2,555,958	656,425·814	£2,555,958 0 3
Half-sovereigns	1,131,500	145,297·076	£565,750 9 9

The total number of sovereigns and half-sovereigns issued in ten years, from 1851 to 1860, inclusive, was as follows:—

	Number of Pieces.	Weight in ozs.	Value.
Sovereigns. .	48,911,848	12,561,630·726	£48,911,849 12 2
Half-sovereigns	14,416,569	1,851,245·511	£7,208,287 4 1

In 1860 the silver coins issued were as follows:—

Crowns . . . . None.
Half-crowns . . . None.

	Number of Pieces.	Weight in ozs.	Value.
Florins . . .	635,580	231,120·000	£63,558 0 0
Shillings . .	1,671,120	303,840·000	£83,556 0 0
Sixpences . .	1,100,880	100,080·000	£27,522 0 0
Groats . . .	None.		
Fourpences .	4,158	252·000	£69 6 0
Threepences .	3,410,088	155,004·000	£42,626 2 0
Twopences .	4,752	144·000	£39 12 0
Pence . . .	7,920	120·000	£33 0 0

The following statement refers to the silver coinage for the ten years from 1851 to 1860:—

	Number of Pieces.	Weight in ozs.	Value.
Crowns . . .	466	424·000	£116 12 0
Half-crowns .	1,493	679·000	£186 14 6
Florins . . .	15,633,372	5,684,862·850	£1,563,337 5 7
Shillings . .	23,025,506	4,186,456·050	£1,151,275 8 2
Sixpences . .	21,735,183	1,975,925·900	£543,379 12 5
Groats . . .	1,880,874	113,932·450	£31,347 18 5
Fourpences . .	41,580	2,520·000	£693 0 0
Threepences .	13,605,101	618,413·700	£170,063 15 4
Twopences . .	47,520	1,440·000	£396 0 0
Pence . . .	78,408	1,188·000	£326 14 0

In the year 1860 the copper and bronze coinage issued was as follows:—

	Number of Pieces.	Weight. Tons.	cwts.	Value.
Copper Pence . .	32,256	0	12	£134 8 0
Bronze Pence . .	5,053,440	47	0	£21,056 0 0
Copper Halfpence .	None.			
Bronze Halfpence .	6,630,400	37	0	£13,813 6 8
Copper Farthings .	None.			
Bronze Farthings .	2,867,200	8	0	£2,986 13 4

The following statement refers to the copper coinage for the ten years 1851 to 1860, including the bronze coinage first issued in the last named year:—

	Number.	Weight. Tons.	cwts.	qrs.	lbs.	ozs.	Value.
Pence . . .	23,232,384	385	3	0	0	0	£96,801 12 0
Halfpence . .	35,739,421	307	14	2	13	15	£74,457 2 6½
Farthings . .	22,456,276	99	1	3	16	14	£23,391 19 1
Half-farthings	3,535,776	8	4	1	19	8	£1,841 11 0

The total value of copper coined in the ten years 1851-60 amounted to £196,192 4s. 7½d., the purchase value of the copper being £91,497 8s. 3d.

In 1860 the value of the copper and bronze coinage was for the former £134 8s., and for the latter £37,856, the purchase value of the metal being only £9,185 2s. 11d., so that it will be seen that our copper coins are tokens much below their nominal value. The cost of coinage is not included in this estimate.

With respect to silver coinage, Government purchases from time to time worn silver coinage from the Bank of England, at its nominal value, for re-coinage. The following particulars refer to the year 1860 :—

Weight in ozs.	Nominal value.	Mint value, at 5s. 6d. per oz.	Loss by re-coinage.
357,902·538	£113,000	£98,423 3s. 9d.	£14,576 16s. 3d.

Under the same heads, the following are the amounts for the ten years 1851-1860, inclusive :—

2,082,057·973	£656,268	£572,465 18s. 5d.	£83,802 1s. 7d.

In 1860 silver bullion was purchased in the market at 61¾d. per oz. ; in 1859 at 61⅝d.

COIR, see Cocoa-nut.

COKE, see Carbon.

COLLIERY, see Coal.

COLOCYNTH, a valuable medicinal agent derived from the bitter cucumber (*Cucumis colocynthis*), growing in Turkey, India, &c. The drug consists of the dried pulp, which is white, spongy, and of a nauseous and bitter taste, but without smell. When adulterated, or badly dried, it is of a dirty brown or deep grey colour. This medicine, which is a powerful drastic cathartic, is too violent to be administered alone, but it is given in union with other medicines. Camphor mitigates its violence.

COLOUR, see Light—Photography.

COLUMBIUM, a rare metal, found in the Swedish minerals *tantalite* and *yttro-tantalite*, and hence sometimes called Tantalum. (Ta 68·8.)

COMB. The materials employed in the manufacture of combs are wood, horn, tortoiseshell, ivory, bone, and metal. The preparatory processes for the two principal materials will be described under Horn and Tortoiseshell. The materials are first prepared in the form of *plates*, and the methods of cutting the teeth in these have led to some ingenious contrivances. The old method of doing this is by means of a double saw, called a *stadda*, Fig. 599; it has two blades, so contrived as to give with ease and exactness the intervals between the teeth of combs, from the coarsest to those which have from 40 to 45 teeth in the inch. The blades or plates of the saw are made of thick steel, and are ground away on the edge, as at *a* or *b*, as thin as the notches in the comb, and they have from 10 to 20 points in the inch of slight pitch. [See Saw.] The plates are fixed in two grooves of the stock by means of the *stuffing*, which consists of two long wooden wedges, or folds of brown paper ; contact between the plates is prevented by a thin slip of metal, called a *languid*, *l*, which is of the thickness of the teeth required in the comb *c*. One blade is in advance of the other from $\frac{1}{16}$ to $\frac{1}{4}$ of an inch ; at the first process a notch nearly of the full depth is made in the comb, and a second notch is commenced ; at the next process the notch in advance is deepened, and a third commenced, and so on consecutively. By this means the teeth can be cut in a regular manner, for the very action of cutting out one tooth scores out a place for the saw for the next adjacent tooth. The openings thus formed are afterwards thinned out and finished by means of thin wedge-shaped files, called *floats*. Some of these files are shown in section in Figs. 602—606, the teeth being shown at the points indicated by the double lines ; *a* is a *float*, *b* the *graille*, *c* the *found*, *d* the *carlet*, *e* the *topper ;* these names are corruptions from the French, and indeed the art of comb-cutting is almost entirely derived from the French. *f* represents what is called a *quannet*, a sort of rasp, with coarse-filed teeth ; this is the ordinary flat file of the comb-makers, and in using it the work is mostly placed on the knee as a support.

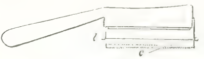


Fig. 599.

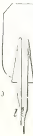


Fig. 600

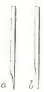
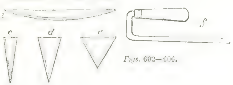


Fig. 601.



Figs. 602—606.

The introduction of the circular saw led to some improvement in comb-cutting, especially with boxwood or ivory as the material. In a machine invented by Messrs. Pow and Lyne, the plate is fixed in a clamp suspended on two pivots parallel with the spindle of the circular saw. By the revolution of the handle, a cam first depresses the ivory on the revolving saw, cuts one notch, and quickly raises it again ; the handle in completing its circuit shifts the slide that carries the suspended clamp to the right, by means of a screw and ratchet movement. The teeth are cut with great exactness, and as quickly as the handle can be turned ; they vary from about 30 to 80 teeth in the inch, and such is the delicacy of some of the saws that even 100 teeth may be cut in an inch of ivory : the saw runs through a cleft in a small piece of ivory, fixed vertically and radially to the saw, to act as the ordinary stops, and prevent it from being bent or displaced sideways. Two combs are usually placed one over the other and cut at once ; occasionally the machine has two saws, and cuts four combs at once.

In making small side-combs of tortoiseshell the material is economised by the process of *parting*, as it is called. This method is said to be the invention of an artisan named Ricketts, who was led to it by being engaged in the production of ornamented tortoiseshell combs, [see HORN and TORTOISESHELL,] in which the decorated parts were formed by the pressure of cutters. A machine for making parted combs was described by Mr. Rogers in the 49th vol. of the Transactions of the Society of Arts. It has since been remodelled and improved by Mr. Kelly. The following is from Mr. Rogers's description:—*pp*, Fig. 607, is a plate supporting the other parts, and is secured by screws to any suitable bench; *h* is a winch or handle attached to the axle *a*; *u u* are upright pieces, in which the two ends of the axle work, and *u′* is another upright, between which and *u* the crank of the axle is situated. From the bottom plate *p* is a curved projecting piece, on which is hinged the bar *b*; at the end of this bar is a collar *c*, secured by a screw, and connected by means of a link with the cranked part of the axle. When the axle is turned round by means of its winch an alternate up and down motion is given to the bar *b*; *l* is a loop in which the bar works, and which prevents it from swerving to either side; *k* is the cutter, and *t* a piece of tortoiseshell, out of which two parted combs are to be made. The cutters Nos. 2 and 3 consist of two sharp blades of steel bent outwards a little at one end, between which are placed wedge-shaped pieces, so as to cause the blades to diverge from each other at the bent end by any required distance; at the other end the blades come nearly but not quite in contact, and this space is filled up by the insertion of the piece No. 4, the sharp tooth of which is so adjusted as to be even with the edge of the blades. When, therefore, this compound cutter is pressed down on the surface of the tortoiseshell, a tooth, such as is shown in No. 5, will be formed. But in order to make a succession of such teeth it is necessary that the piece of tortoiseshell shall have a progressive motion, and that this motion shall be suspended while the cutter is making its blow. These two conditions are effected thus:—in front of the bed on which the tortoiseshell *t* is laid is a rectangular opening, into which a heated bar is put, which, by keeping the tortoiseshell warm, prevents it from splitting by the action of the cutter. The bed slides in a dovetail groove made in the plate *p*, and has a hollow screw in that end of it which is adjacent to the toothed-wheel *w*. From the centre of this wheel projects a solid screw which turns in the hollow one, and consequently moves the bed in one direction or the other, according as the toothed wheel is turned one way or the other. The wheel *w* receives its motion from the wheel *w′*, which being placed on the axle *a*, is turned together with it by the winch *k*. But the wheel *w′* has teeth only on part of its circumference, and therefore, while this is in continued motion, will give an alternation of motion and rest to the wheel *w*, and consequently to the piece of tortoiseshell *t*. While this latter is at rest the cutter makes its stroke, and while the cutter is rising to make another stroke, the piece of tortoiseshell moves through a space equal to the interval between one tooth of the comb and the next. When these actions have been repeated along the whole length of the tortoiseshell, Fig. 608 is produced, which is the full size or nearly so, and a slight pull will part the two pieces, each of which is a separate comb. Such combs are called *parted*, the saw not being used on them, and they are often made of fine stained horn instead of tortoiseshell.

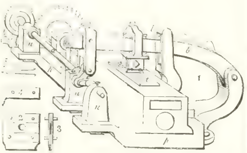


Fig. 607.

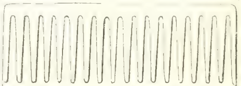


Fig. 608.

COMBUSTION, a chemical process, in which two substances at least enter into combination, and heat and a new compound are the results. Thus, when antimony in powder, or copper in the form of thin leaf, is presented to chlorine, a combination is instantly effected between these bodies, and a chloride of antimony or of copper is the result, attended at the moment of combination with heat and light. It is usual to reckon five supporters of combustion, viz. oxygen, chlorine, iodine, bromine, and fluorine. Of these, the first is by far the most important. It is one of the constituents of the atmosphere and of water; it enters abundantly into the composition of most bodies in their natural state, and is altogether so important that without it no animal could live, no plant could grow, and, generally speaking, no flame could burn; the other four supporters of combustion, as they are termed, would not support animal or vegetable life.

Before the discovery of oxygen gas combustion was explained by supposing that all combustible bodies contained a certain principle called *phlogiston*, the presence of which enabled bodies to burn. It was further supposed that when a body burned, phlogiston was liberated, and that when a body had lost phlogiston it ceased to be combustible; it was then said to be *dephlogisticated*. The heat and light which accompany combustion were attributed to the rapidity with which phlogiston was evolved.

But according to this hypothesis, a combustible body having undergone the process of combustion ought to have lost weight, whereas it was found in many cases that the results of combustion were *heavier* than before combustion had taken place. The discovery of oxygen gas proved fatal to the phlogiston theory. Lavoisier burnt phosphorus in a jar of oxygen, and observed that much of the gas disappeared, and that the phosphorus gained in weight; that the increase of the one was in the ratio of the decrease of the other. Iron wire burnt in oxygen gas gave a result equal to the wire employed, plus the weight of the oxygen that had disappeared. Mercury being confined in a vessel of oxygen, and exposed to the temperature of about 600°, the gas combined with the metal, and the resulting oxide being heated to about 900°, was reconverted into oxygen gas and metallic mercury; the quantity of oxygen thus recovered answering precisely to that employed in the first instance to produce the oxidation.

In ordinary cases of combustion the heat evolved does not depend upon the combustible, but upon the quantity of oxygen that enters into combination. Thus, according to Despretz, a pound of oxygen, in combining respectively with hydrogen, charcoal, alcohol, &c., evolved in each case nearly the same amount of heat, each raising 29 lbs. of water from 32° to 212°. A given weight of different combustibles gives the comparative quantities of heat represented by the following figures:—

	lbs. of water.		
1 lb. of pure charcoal raised .	78	from 32°	to 212°.
,, common wood charcoal	75	,,	,,
,, baked wood	36	,,	,,
,, wood, holding 20 per cent. of water . .	27	,,	,,
,, bituminous coal . .	60	,,	,,
,, turf	25 to 30	,,	,,
,, alcohol	68	,,	,,
,, oil, wax	90	,,	,,
,, ether	80	,,	,,
,, hydrogen	236	,,	,,

The products of combustion in oxygen or its compounds form the three great classes of *acids*, *alkalies*, and *oxides*.

COMPASS, an instrument consisting of a magnetic needle or bar, mounted on a fine centre, enclosed within a shallow box or metallic case, and furnished with a plane circular card, denoting the *chief* or *cardinal* points of the horizontal plane about us. The term *compass* is immediately derived from the card which *compasses* or involves as it were the whole plane of the horizon. The compass needle N S, Fig. 609, is usually a light bar, set edgewise upon an agate centre; sometimes it consists of a thin piece of steel plate tapering from the centre to the extremities, and it may be of any dimensions according to the size of the compass required. The compass or card which indicates the various points in the horizon with reference to the direction of the magnetic needle, is either fixed in the case immediately under the needle and separate from it, or it is attached to the needle itself, as in Fig. 611, so as to traverse with it. In the former case it is made of cardboard or metal; in the latter, of some very light substance not liable to warp from heat or moisture, such as a thin plate of talc.

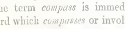


Fig 609.

In the magnetic compass, the plane of the horizontal circle is divided into 32 parts by lines supposed to be drawn diametrically through the circle. These, as practically applied to the compass card, are called *points of the compass*, or in nautical language, *rhumbs*. In marking the compass card Fig. 610, the circle is first divided into two semicircles by a diameter N S, which denotes the line of the magnetic meridian; and the north point, as being the most elementary or great point of reference, is usually distinguished by an ornamental arrow or fleur-de-lis. A diameter E W is next drawn at right angles to the other, by which we obtain the east and west line, and thus we have the 4 principal or elementary cardinal points. The quadrants of the circle between these 4 points are further and equally divided by 2 other diameters producing four new rhumbs or points. These are named from their relative position in the compass. The point midway between N and E, for example, being compounded as it were of the two directions, is termed north-east, and is marked N E. That midway between N and W is termed north-west, and marked N W: that between S and W is termed south-west, and marked S W: that between S and E is south-east, and marked S E.

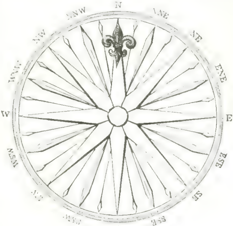


Fig. 610. THE COMPASS CARD.

We thus obtain 8 principal points or rhumbs, and by continuing the division by diameters, bisecting the arcs contained by these first 8 points, we obtain an additional 8 points, making in all 16 points: these additional points are named as before from their position in the compass. The point midway between N and NE is termed north-north-east, as being nearer north than east, and is hence marked with two letters N, thus NNE. In a similar way the point between east and north-east is termed east-north-east, as being nearer the east, and is marked thus, ENE; and so on of the remaining bisected arcs: thus we have the points NNW and WNW for the points between north and west; SSW and WSW for the points between south and west; SSE and ESE for the points between south and east.

By continuing to bisect the arcs included between these points, we again double the number of rhumbs, and obtain 16 additional points, making in all 32 points: these are also named from their position in the compass, with the addition of the word *by*. Thus the point midway between N and NNE is called north by east and is marked N by E; that between N and NNW, north by west, and is marked N by W; the point between NE and NNE is called north-east by north, and is marked NE by N, and so on, leaning for the designation towards the nearest of the four elementary cardinal points. Thus the point midway between E and ENE is termed east by north and is marked E by N. In this way we arrive at 32 rhumbs or divisions of the circle into points, which taken in succession from the first or principal point, north, and carried round the circle in either direction, east or west,—suppose in the east direction, will stand thus:—

N.	E.	S.	W.
N by E.	E by S.	S by W.	W by N.
NNE.	ESE.	SSW.	WNW.
NE by N.	SE by E.	SW by S.	NW by W.
NE.	SE.	SW.	NW.
NE by E.	SE by S.	SW by W.	NW by N.
ENE.	SSE.	WSW.	NNW.
E by N.	S by E	W by S.	N by W.

An enumeration of these successive points from memory is called *boxing the compass.* More minute divisions of the compass card are estimated by what are called *half* and *quarter points*, each point being divided or supposed to be divided into 4 equal parts, so that any small angular quantity between either of the 32 divisions or points just enumerated, as, for example, between N and N by E would be termed, north-a-quarter-east, or north-half-east, or three-quarters-east, as the case may be: we then arrive at north by east, and so of all the other points. Thus north by west, a little to the north or west, would be called north by west a quarter, or half, &c. north, or a quarter, or half, &c. west, as the case may be.

For more refined purposes, the compass is enclosed by a graduated circle, divided in the usual way into 360 degrees, by which the rhumbs are estimated in angular quantities, each rhumb or point being the $\frac{1}{32}$d part of 360°, or $\frac{360}{32} = 11° 15'$: a half-point will be then 5° 37′ 30″; a quarter-point 2° 48′ 45″.

When the compass-card is fixed to the box or case in which it is enclosed, and the needle is allowed to traverse over it, we have what is usually termed a *land compass.* It is commonly used by travellers for determining the different points of the horizon, the box being turned so as to bring the north and south points of the card immediately under the north and south poles of the needle. In this case, all the other points, as referred to the magnetic meridian of the particular locality, are correctly placed. The land compass is also occasionally employed in the measurement of angles in surveying instruments. It may be, for general purposes, of any moderate size, from that of a common seal up to the diameter of a foot. The land compass has usually a spring stop under the needle, by which it may be thrown up and retained clear of the point when not in use.

A fixed compass-card, as applied in the land compass, could not be used on ship-board for determining the position of the cardinal points in reference to the magnetic meridian, because the vessel is continually varying its position, and is in continual motion: it becomes therefore requisite to construct the compass-card of some light substance, not liable to warp or to be injured by heat and moisture. This is attached to the needle itself, so as to admit of both card and needle traversing together. If the needle be fixed to the card with the north and south poles immediately under the north and south poles of the compass, then all the points of the card will be correctly placed in reference to the magnetic meridian of the place, in whatever direction the vessel be turned; that is to say, supposing that no disturbing influence from iron or other cause exist in the ship itself. This is therefore the principal distinction between the land and sea compass. In the sea, or *mariner's compass*, Fig. 611, the magnetic needle, together with its card, S W N E, is accurately poised on a fine central point within a bowl or case, A, of glass, metal, or wood; and in order to prevent any disturbance from the pitching and rolling of the ship, this bowl is set within a ring of metal, C A D, upon two axial pivots, projecting from its opposite sides, one of which is seen near A. The ring, in its turn, is set also upon axial pivots, at C and D, in a line at right angles to the former, and which are supported either within a second semicircular or vertical ring, C B D, or on pivot notches in two brass plates fixed at C and D to the box or case in which the whole is usually enclosed. [See BINNACLE.] The centre of gravity of the mass is frequently kept far below these axial pivots of suspension by a ring or small mass of lead, attached to the bottom of the compass-bowl. The two brass circles within which the compass-bowl is thus supported are called *gimbalds;* and it is evident that, by these, the card and needle will generally be preserved in a plane perpendicular to that of

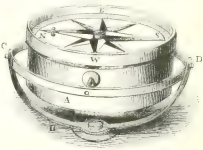


Fig. 611. THE MARINER'S COMPASS.

the point of suspension. In fact, any rolling motion transverse to the axis C D moves the ring C A D upon the axis C D, and any similar motion transverse to the axis A moves the ring C A D upon the inner axis A; the interior bowl, with the needle and card, being all the while maintained in a vertical position by the force of gravity. This form of the compass, although chiefly employed to guide the mariner across a trackless ocean, has still many other important practical applications. For an account of these, we refer the reader to Sir W. Snow Harris's Treatise on Magnetism, published in Weale's "Rudimentary Series," in which he will find an account of the azimuth compass, the dipping needle, and other magnetic instruments.

COMPASSES, an instrument in its simplest form consisting of two legs, movable about a joint. The extremities of the legs are furnished with points, which may be set at any required distance from one another, and thus be used to measure and transfer distances, and to describe arcs and circles. "The points of the compasses should be formed of well-tempered steel, that cannot be easily bent or blunted; the upper part being formed of brass or silver. The joint is framed of two substances; one side being of the same material as the upper part of the compasses, either brass or silver, and the other of steel. This arrangement diminishes the wear of the parts, and promotes uniformity in their motion. If this uniformity be wanting, it is extremely difficult to set the compasses at any desired distance, for, being opened or closed by the pressure of the finger, if the joint be not good, they will move by fits and starts, and either stop short of, or go beyond, the distance required; but when they move evenly, the pressure may be regulated so as to open the legs to the desired extent, and the joint should be stiff enough to hold them in this position, and not to permit them to deviate from it in consequence of the small amount of pressure which is inseparable from their use. When greater accuracy in the set of the compasses is required than can be effected by the joint alone, we have recourse to the *hair compasses*, in which the upper part of one of the steel points is formed into a bent spring, which, being fastened at one extremity to the leg of the compasses, almost close up to the joint, is held at the other end by a screw. A groove is formed in the shank, which receives the spring when screwed up tight; and by turning the screw backwards, the steel point may be gradually allowed to be pulled backwards by the spring, and may again be gradually pulled forwards by the screw being turned forwards."—*Heather*. There are also compasses with movable points; the end of one of the shanks being formed with a spring, which holds firmly the movable point, or a pencil or ink-point, or a pen-point with a dotting-wheel, or a lengthening-bar, as may be required. To describe small arcs or circles, a small pair of compasses, called *bow compasses*, with a permanent ink- or pencil-point, are used. They are formed with a round head, which rolls with ease between the fingers. For copying and reducing drawings, compasses of a peculiar construction are used, consisting of a double pair of compasses, two legs being above and two below the central joint: the simplest form of these compasses is that called *wholes and halves*, because the longer legs being twice the length of the shorter, when the former are opened to any given line, the shorter ones will be opened to the half of that line. In this way, all the lines of a drawing may be reduced to one-half, or enlarged to double their length. To reduce or enlarge drawings in any required proportion, a beautiful instrument, named the *proportional compasses*, is used. This, together with *beam compasses*, will be described under PANTAGRAPH. For further information respecting compasses, we must refer to Mr. Heather's Treatise, in Weale's "Rudimentary Series." This is the best and cheapest treatise on the use of mathematical instruments with which we are acquainted.

CONCENTRIC, having the same centre: concentric circles are those described about the same point.

CONCRETE, see BRIDGE, Sec. iii.—MORTARS—and CEMENTS.

CONE. If a straight line A X, Fig. 612, pass through a fixed point O, and be moved through any curve such as A B C, it will trace by its motion a surface, which is called a *cone*. Of this cone, the point O is the *vertex*; the right line, the motion of which produced the surface, is the *directrix*, and the curve A B C which guides its motion, the *generatrix* of the cone. If the generatrix be a right lined figure, the cone will become a *pyramid*. The most usual form of cone is that whose generatrix is a circle. The *axis* of a cone is a line drawn from its vertex to the centre of its circular base. In a *right cone*, the axis is perpendicular to its base; in an *oblique cone*, the axis is oblique to its base. A pyramid and a cone, whose bases and altitudes are equal, have equal volumes; for since all the corresponding sections parallel to the bases are equal, the cone will be composed of a series of plates, equal respectively to those which compose the pyramid. The volume of a cone is found by multiplying the area of its base by one third of its altitude. If a cone and a cylinder have equal bases and equal altitudes, the volume of the cone will be one third of the volume of the cylinder. The volumes of cones being proportional to the products of their bases and altitudes, and the bases being proportional to the squares of their diameters, the volumes will be proportional to their altitudes multiplied by the squares of the diameters of their bases. The area of the surface of a right cone is found by multiplying the length of its side, by half the circumference of its base. The area of the surface of a right cone, is equal to that of a triangle, whose base is equal to the circumference of the base of the cone, and whose altitude is equal to the side of the cone. If a cone

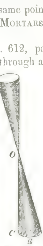


Fig. 612.

be cut by a plane A′ B′, Fig. 613, parallel to its base, the figure with parallel circular bases thus cut off, is called a *truncated cone.* The area of the surface and the volume of a truncated cone, are found by taking the difference of the surfaces, and of the volumes of the whole cone, A O B, and of the cone A′ O B′ which is cut off.

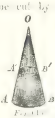


Fig. 613.

A circular cone is produced in the arts by means of the turning-lathe: when the substance to which the conical form is to be given, is kept constantly turning, the cutting tool is moved along the directrix, or side of the cone; as it advances, the circular form is given to the section of the body by its own motion, and the rectilinear form is given to its side by the motion of the tool.

COOLER, see BEER.

COOPERAGE. From the year 70 of the Christian era, the art of making vessels of different pieces of wood seems to have been well known. The invention is ascribed by Pliny to the people who lived at the foot of the Alps. Some of the classical writers on Rural Economy mention such vessels, and describe them as being bound together with circles of wood or hoops. The art was probably introduced by the Romans into Britain, and it seems to have attained its present state of perfection at a very early period.

The occupation of the cooper is divided into several distinct branches. The *dry* cooper makes casks for containing all kinds of goods not in a liquid state, as sugar, currants, flour, &c. The *wet* or *tight* cooper makes casks for all kinds of liquid goods, and this branch is subdivided into *large* and *small* work, which are kept quite distinct. There are also *white* coopers, or those who make tubs, pails, churns, &c.; and there are coopers in *general*, who profess to undertake all kinds of work: it is necessary however, in order to become a skilful cooper, to confine attention to one branch of the trade, and of this the most difficult is that which is devoted to large tight work.

Tight work is made of oak, of which five kinds are used, viz.—Quebec, Virginia, Dantzic, Hambro', and English oak. Small dry casks or *kegs* are chiefly made of Quebec oak.

The figure of a cask is that of two truncated cones or conoids joined together, for the lines are not straight as in cones; but curved from the vertex to the base. The place of junction of the two conoids, or the middle of the cask, is called the *belly* or *bulge*, and the space between the middle and the end, the *quarter*. The wood is chosen from old, thick, and straight trees: the planks are hewn and formed into staves. The French prepare the wood in winter; the staves and the bottoms are then formed, and the cask is *mounted* or put together in summer. Shaping or planing the staves is one of the most difficult, and also the most important parts of the cooper's work. Each stave must form part of a double conoid; it must be broader in the middle, and gradually become narrower, but not in straight lines, towards the two extremities. The outside of the staves across the wood must be wrought into segments of a circle, and be thickest nearer the middle, growing gradually thinner towards the ends. When the staves are dressed and arranged in a circular form, the cooper without attempting to slope them, so that the whole surface of the edge may touch in every point, brings the contiguous staves into contact only at the inner surface, and by driving the hoops hard, he can make a closer joint than could be done by sloping them from the outer to the inner sides. In this, and in giving the proper curve to the staves, consists the principal part of the cooper's art.

In the vaults of various docks are many thousand casks of wines and spirits in bond. The office of *bond*-cooper, as it is called, is an important one; each bond-cooper has the charge of from 1,000 to 2,000 casks, and it is his duty to see that all the casks are in good order, to draw out samples for tasting, &c.

The reader who wishes to follow out the minute details of the cooper's art, is referred to the number entitled "The Cooper," of Mr. Charles Knight's excellent little series, "The Guide to Trade."

COPAL, see VARNISH.

COPPER (Cu. 31·7), a metal known to the ancients, and deriving its name from the island of Cyprus, where it was first wrought by the Greeks. Before the discovery of malleable iron, it was the chief ingredient in the manufacture of domestic utensils, and instruments of war. Copper is sometimes met with in a native state, but more frequently in combination with the metalloids, with oxygen, sulphur, and arsenic. The sulphurets are most abundant, and from them the commercial demands are almost exclusively supplied. The sulphuret combined with sulphuret of iron, forms the well-known *yellow copper* ore. Native copper often crystallizes under the form of small regular octohedrons; these may be also obtained when copper is slowly precipitated from solutions by voltaic electricity. Copper affects the same crystalline form, when a considerable mass melted in a crucible, is left to cool slowly; the part which remains liquid after reposing some time, having been poured off. Chemically pure copper may be obtained by passing a stream of hydrogen over the oxide, heated to redness in a glass tube. If a small quantity of the oxide is operated on in this way, the reduced metal is obtained in thin films, which by reflected light present the characteristic red colour of copper, but by transmitted light are of a beautiful green. Copper is very malleable and ductile; it may be beaten out into thin leaves or drawn out into fine wire. It has great tenacity, being in this respect inferior only to iron. Its density varies from 8.78 for cast copper, to 8.96 for rolled or hammered copper. It has a peculiar taste, and by friction evolves a disagreeable odour. It melts at a strong red heat, which has been fixed by Daniell at 1996° Fahr. At a white heat, it passes off in vapour, which burns in the air with a green flame. At a white heat, copper decomposes the vapour of water. At ordinary temperatures, this metal does not oxidise in dry air; but it changes quickly in moist air; it then becomes covered with a strongly adherent green crust consisting chiefly of carbonate. Copper changes more quickly if an acid vapour be present. **Verdigris** is a subacetate of copper, and is formed by placing plates of the metal in contact with the fermenting marc of the grape, or with cloth dipped in vinegar. Heated to redness in the air, copper becomes quickly oxidized, a black scale covering its surface. Dilute sulphuric and muriatic acids scarcely act upon metallic copper, but dilute nitric acid dissolves it readily. Two oxides are known which form salts. The protoxide or black oxide of copper, (CuO,) is the base of the ordinary blue and green salts. When a salt of this oxide is mixed with caustic alkali in excess, a bulky pale blue precipitate of hydrated oxide, (CuO,HO) falls, which when the whole is raised to the boiling point, becomes converted into a heavy dark brown powder: this is anhydrous oxide of copper, for the hydrate is decomposed even in contact with water. Prepared at a high temperature, the oxide is perfectly black and very dense. The hydrated oxide of copper is used as a pigment or colour for paper-staining, for which purpose it is mixed with glue or sise, with the addition of chalk or alumina. Its blue colour, however, soon acquires a greenish tinge.

The suboxide or red oxide of copper, (Cu_2O,) may be procured by heating in a covered crucible a mixture of 5 parts of black oxide, and 4 parts of fine copper filings. There are various other methods of procuring it. It often occurs in transparent ruby red crystals associated with other ores of copper; it is known as *Ruby copper:* one variety known in Cornwall as *Tile ore,* contains peroxide of iron. The suboxide gives a fine red tint to glass, while that given by the protoxide is green.

Among the more important salts of copper may be noticed the *Sulphate* or *Blue vitriol* (CuO,SO_3+5HO). This salt may be prepared by dissolving oxide of copper in sulphuric acid, or more economically by oxidizing the sulphuret. It forms large crystals of a fine blue colour, which are soluble in 4 parts cold, and 2 of boiling water; heated to 100 it becomes anhydrous, loses its colour and becomes white; if left exposed, it slowly re-absorbs water from the air, and regains its blue colour; or if sprinkled with water heat is evolved, and the blue hydrate is immediately formed. This salt is the source of several blue and green colours, it is used by dyers and calico-printers; also in some kinds of writing ink, but with this inconvenience, that in writing with steel pens, metallic copper is precipitated upon the steel, and the pen gets clogged; it is on this principle, that by immersing pieces of iron in the waters of copper-mines, which often hold copper in solution, metallic copper is recovered. Grain steeped in a solution of this salt, is said to be not liable to the smut, and timber or planks similarly treated, will be preserved from dry rot. Wood-work, cellars, &c., subject to mouldiness should be washed with a solution of blue vitriol. This salt is also a powerful preservative of animal substances, which when imbued with it and dried, remain unaltered.

The commercial sulphate of copper is manufactured in the following manner:—In a wooden vessel, lined with stout sheet-lead, oil of vitriol is poured, to which are added *copper scales*,[1] until a saturated solution of sulphate of copper is obtained, the operation being assisted by the aid of steam blown in through a lead pipe dipping to the bottom of the vessel: the mother liquor of a previous operation is then added, and the whole left to crystallize. The crystallizing vessels are of wood lined with lead: they are placed in a warm room, and a crop of crystals is usually obtained in 4 or 6 days. The mother liquor being poured off, the crystals are drained, and packed in casks for sale: in some cases they are previously dried. It is not unusual to add the *pickle* or *dipping-liquor* used by the coppersmith for the purpose of cleaning copper, brass, &c.,[2] to the solution of copper in sulphuric acid; and in some cases the pickle is used alone, for the purpose of furnishing crystals of this salt, the excess of acid being neutralized by oxide of copper.[3]

By adding carbonate of soda in excess to a solution of sulphate of copper, the precipitate is, at first, pale blue and flocculent, but by heat it becomes of a sandy texture and of a green colour. In this state, it contains CuO_3CO_2+CuO,HO. This carbonate is prepared as a pigment under the name of *blue verditer*. Malachite has a similar composition; it is found in great beauty in the Uralian mountains of Siberia. Chloride of copper, $CuCl+2HO$, is easily prepared by dissolving the black oxide in hydrochloric acid, and concentrating the resulting green solution. It forms green crystals very soluble in water and in alcohol: it gives a green colour to the flame of alcohol. Dichloride of copper $Cu2Cl$ is obtained by exposing copper filings to the action of chlorine. It may also be obtained in various other ways. When this salt is moistened and exposed to air it becomes green, and is converted into a compound of chloride and oxide of copper, which has been termed Submuriate of copper or *Brunswick green*.

Of the compounds of copper and sulphur, the most interesting is the disulphuret (Cu_2S.) It is found as an ore chiefly in primitive countries. It occurs in Cornwall and Yorkshire in great beauty, crystallized and massive. Its colour is grey: its lustre shining and metallic: its sp. gr. 5.69 to 5.73. Its primitive form is a six-sided prism, which passes into the dodecahedron with triangular faces and its various modifications. But by far the largest proportion of the copper of commerce is derived from the ferrosulphuret, or copper pyrites, or yellow copper ore.

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(1) Copper scales consist of a mixture of metallic copper with oxides of that metal, and are obtained, in the form of thin plates or scales, from the sheets of copper which have undergone the process of annealing by being heated in a furnace or forge. A portion only of these scales is dissolved by the acid, the residue is washed, dried, and sent to the copper-furnace to be melted.

(2) In Birmingham some hundred tons of dipping liquor are produced every year, and used in the manufacture of sulphate of copper. The salt is very impure: it often contains a large portion of zinc, which may be seen in the form of slender white needles on the surface of the dark blue crystals. Nickel, lead, arsenic, and antimony are also sometimes present in these crystals.

(3) Pharmaceutical Journal for April, 1851.

This occurs in various forms, its primitive crystal being the regular tetrahedron.

The metallurgical history of copper presents so many important and interesting features, that we propose to devote a considerable space to the subject. The methods adopted for procuring the ore and raising it to the surface, stamping, dressing, &c., will be described under METALLURGY—MINE—MINING. Our present object is to give a brief notice of the copper trade, and to detail somewhat fully the various processes concerned in the smelting of the ore.

The copper smelting works of this country are situated at Swansea in the Bay of Bristol; they are by far the largest in the world, they are highly prosperous, and many of the circumstances connected with them are unparalleled in the history of metallurgy.

The ores of metals generally contain a large proportion of matter, the value of which is incomparably less than that of an equal weight of metal contained in them. To save the expense of carriage the ore is usually dressed in the vicinity of the mine, and the position of the smelting works is most commonly determined by that of the metallic lodes. Thus in all the great metalliferous districts, in the Altai, and the Ural Mountains, in Sweden, Norway, Hungary, the Tyrol, Germany, &c., the ore has rarely to travel more than a few miles to the place where it is to be smelted. In the United Kingdom, however, the copper ore is sent by sea from the numerous mines of Cornwall, Devonshire, Wales, Ireland, and the Isle of Man, to South Wales to be smelted; distances varying from 60 to 250 miles, and this traffic has not added more to the expense of smelting than would be occasioned on the continent by a mean transit of 10 times less the distance. Moreover, during the last 20 years, Swansea has been supplied with ores from the shores of Europe, from Cuba, Mexico, Columbia, Peru, Chili, Australia, and New Zealand, so that at the present time there is more copper smelted in South Wales than in all the other countries of the New and of the Old World taken together.

The copper trade of this country is therefore of great importance, although vastly inferior to that of iron: indeed there are as many hands employed in one of our great iron works as in all the copper works of the kingdom. There are 19 copper works in England and Wales, all of which (with the exception of two small works, one in Liverpool and the other in Anglesea,) are situate in the Swansea Valley above the town, or within a distance of 14 miles from it. Swansea owes her distinction in this respect to the possession of a commodious and safe harbour, with a coal field behind it. The Admiralty Hydrographers remark:—"Of all the ports in the Bristol Channel, there is perhaps none more favourably situate than that of Swansea, for it is an important fact, that Swansea harbour is accessible to any stranger that may arrive in the bay when it is blowing too strong for pilots to get off." The width of the bay is about 10 miles, and the town is situate in the centre of the curve.

The ores of Cornwall and Devonshire are sold at or near the mines where they are raised. Foreign ores are brought to Swansea to be sold. The Cornish ores are roughly prepared for sale in the following manner:—When the ores are brought to the surface, they are divided into three portions: the first consisting of pieces about the size of the fist, called *spalling stuff;* the second termed *picking rough*, consisting of such smaller pieces as will not pass through a sieve, named from the size of the meshes, a *three-quarter-inch griddle;* and the third, of all that passes through the sieve, called *shaft small*. The larger pieces being broken to about $1\frac{1}{2}$ inch square, are mixed with the picking rough, and the whole is divided into *prills*, or lumps of pure ore; *dradge*, or ore mixed with other substances; and *halvans* or *leavings* which contain but a small quantity of ore. The prills are broken into pieces of about $\frac{1}{2}$ inch square, which is performed by females with large flat-polled two-handed hammers; this portion of the ore is then ready for the market. If the dradge contain but little iron pyrites, it is broken to a still smaller size than the prills, and is then jigged in a sieve of about 5 holes to the square inch: by which means it is separated into 4 parts: 1, that which passes through the sieve, called *hutch-work*, which is usually fit for sale; 2, that portion occupying the bottom of the sieve, called *ragging*, which is also in a marketable state; 3, the middle part of the contents of the sieve which is again broken and jigged; 4, that at the top of the sieve, which is put among the leavings. If the dradge contain much iron pyrites, it is *picked* by females and children: the pieces being broken to about $\frac{5}{8}$ inch square, and the impurities picked out by hand. By continuing these operations of picking, breaking, and sifting, the ore is rendered fit for sale. Some of the ores are so soft, that exposure to water would occasion loss. The leavings or refuse are, however, sometimes stamped and buddled in the same manner as tin ore. [See METALLURGY.]

The determination of the value of the ores offered for sale is difficult, and it is admitted, that the precise results obtained by the chemists, are inferior in practice to those adopted by the mining agents. Although these may be only an approximative analysis, and occasionally lead to a depreciation in the price offered for the ore, the mine owners are too well aware that their interests are identical with those of the smelters, to disturb the method of selling the ores which has existed for very many years. The plan adopted is as follows:—When the miners of a certain place have to sell a quantity of ore, advertisements are inserted in the local journals appointing the days for sale, and the days when specimens of the ore may be taken. The places of sale are Camborne, Redruth, Truro, and Pool, on account of their central position. The sales always take place on a Thursday. Each of the Welsh copper companies has two agents in Cornwall, one of whom takes the sample, of which the other makes the assay. On the day appointed the agents meet at the mine, dine at the expense of the owner, and take samples. The weight of each lot rarely exceeds 100 tons, and is seldom less than 5 tons: it is usually between 20 and 80 tons. During the 15 days between this and the day of sale, the agent makes his report to and receives instructions from his employers for the regulation of his biddings. On the day appointed for sale, the agents meet the mine-owners at an inn in one of the above-named towns; the meeting is usually presided over by the owner who has the largest quantity of ore for sale. The sale commences at noon with closed doors, and the proceedings are conducted in a very quiet manner, although as much as from 20,000*l.* to 40,000*l.* worth of ore is about to be contended for. The chairman begins by reading the number of tons and the description of the first lot on his list. Each bidder writes on a slip of paper called a *ticket*,[1] the price which he has to offer and gives it to the president. The weight of each lot not having been rigorously determined, the price offered refers to the ton of *dry* ore. All the tickets being collected, the president reads slowly the prices offered, and the agents enter them in papers ruled for the purpose. The president assigns the lot to the highest bidder, and states the difference between the highest and the lowest price offered. Should any two agents make the same offer, the lot is divided equally between them. A second lot is then put up, and 10 minutes is allowed for the agents to make their calculations, which may be to a certain extent influenced by the result of the first sale. The following is a specimen of one of the papers as filled up by the agents while the president is reading over the tickets. The prices underlined are those at which the different lots were sold.

SALE AT REDRUTH, 29TH OCTOBER, 1848.

	First Lot.			Second Lot.			Third Lot.			Fourth Lot.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
1st Company....	5	4	0	7	13	0	4	12	6	4	5	0
2d ,, ...	5	6	6	7	14	6	4	8	6	4	4	0
3d ,, ...	5	12	6	8	4	0	4	11	0	4	9	6
4th ,, ...	5	13	0	8	3	0	4	10	0	4	6	0
5th ,, ...	5	11	6	8	5	6	4	13	0	4	11	6
6th ,, ...	5	11	0	8	0	0	4	12	0	4	6	0
7th ,, ...	5	11	6	8	0	6	4	14	6	4	12	0
8th ,, ...	5	14	0	8	1	0	4	15	0	4	8	6

After the sale the agents proceed to the mine, and the lots are delivered: the weight of each lot is exactly ascertained in the moist state, and the agent then finds, by experiment, what deduction is to be made for moisture. One month after the sale the founders forward to the mine owners bills payable one month after date, for the amount of their respective purchases. In the year 1848 the number of tons of copper ore sold in Cornwall amounted to 153,120, which produced 873,436*l.* 10*s.* 6*d.* In the same year 47,611 tons of foreign copper ores were sold at Swansea, which produced 641,056*l.* 10*s.* 6*d.*: these fetch a higher price than the English ores, not only on account of many of them being richer, but also from their being higher dressed before they are shipped for England.

The mines of South America, the foreign West Indies, and Australia, which supply the ores, are worked chiefly by English adventurers, the head quarters of the several companies being in London. These companies charter vessels of large burden to convey the ores to Swansea, where they are stowed in yards, crushed, sampled, and sold to the copper masters at the ticketings. Some of the ores are crushed by passing them through rollers. A correspondent of the *Morning Chronicle* describes a visit to one of the ticketings which are held every fortnight at the chief hotel in Swansea. He says:—

"The proceedings were characteristic, and were remarkable for the total absence of that kind of excitement which often accompanies business transactions on so extensive a scale. At a long table, arranged with blotting-paper, pens, and ink, as at a committee meeting, the proprietors or agents of the copper works take their seats. At 12 o'clock the chairman takes the chair, and opens the business by saying: 'I'll take offers for the first four lots of Cobre, Burra Burra,' or whatever may be the number of the lots and the kind of ore to be sold in the first group. Upon this the buyers, who have previously had each lot assayed, and ascertained its worth, enter on a small billet of paper the amount they bid per ton for each lot, fold the paper, and hand it to the chairman. When all the biddings are received, the chairman opens them in a prescribed order, and calls out the bidding, which the parties present enter into a blank form supplied for the purpose; and when he has gone through the whole, he names the buyer, and calls out the 'excess,' *i.e.* the sum per ton which the buyer's bidding exceeds that of the highest bidder below him. The chairman then offers the next group of 'parcels,' and the same routine is pursued as on the first occasion. Scarcely a word is spoken. In this manner sales, in the course of an hour, are effected, amounting to between 20,000*l.* and 50,000*l.* At the ticketing held on 3d January, there were thus sold 1,447 tons of Cuba and South Australian ores, the proceeds amounting to 28,925*l.* 4*s.* 6*d.* The cargo of Burra Burra ore, brought by one ship, 'The Ancient Briton,' appears to have realized 14,666*l.* 4*s.* 6*d.* of the above total. What struck me as very remarkable, was the nicety with which the calculations of the worth of the ores had been made by the buyers. The system of assaying must have been carried here to very high perfection; for the 'excess' of the highest bidder over the bidder next below him in the case of 15 lots which I saw sold, was in two instances 2*s.* 6*d.* a ton, in five 1*s.* 6*d.* a ton, in two 1*s.* and in six only 6*d.* a ton. The price given per ton for Irish ores sold at the ticketing I attended, varied from 8*l.* 10*s.* 6*d.* down to 3*l.* 15*s.*"

The perfection in the system of assaying, which the writer here speaks of, ought rather to be called that kind of practical knowledge which results from long experience, guided and modified by the condition and prospects of each company, and the price of copper in the market.

The founders have dépôts in the principal ports of Cornwall and Devonshire, where the ore is stored. It

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(1) Hence this system of sale is called *ticketing*, and the days of sale *ticketing days*.

is transported to Swansea in vessels of 100 to 150 tons, which draw very little water, so that they can discharge their cargoes at all states of the tide in the yards of the companies, which are nearly all situated at the edge of the river, R, Fig. 620. The average cost of freight is about 4s. per ton, and the vessels return to Cornwall with cargoes of Welsh coal, the freight of which pays the greater portion of the expenses of the voyage. Cornwall and Devon send on an average to Swansea 165,000 tons of ore, and Ireland 35,000 tons. A vessel of 130 tons arriving at one of the company's quays at 5 A.M., will have discharged her cargo by 3 P.M.

Two-thirds of the ore which is brought to Swansea consist of copper pyrites; the remaining third consists of the green carbonate, the red and black oxides, the hydrosilicate, the phosphate, the arseniate, and native copper: most of these are associated with quartz and iron pyrites. These ores have been grouped into five classes according to their chemical composition, and the proportion of copper contained in them:—

1st Class,—Copper pyrites containing a large proportion of iron pyrites, and very little oxide of copper. The gangue is quartz and earthy matters. The amount of copper varies from 3 to 13 per cent.

2d Class,—Copper pyrites similar in composition to the preceding, but containing from 15 to 25 per cent. of copper.

3d Class,—Copper pyrites containing a very small proportion of iron pyrites, and substances which injure the quality of the copper, but a large proportion of oxide of copper. Their gangue is essentially quartzose. They contain from 12 to 20 per cent. of copper.

4th Class,—Ores composed principally of oxides of copper, mixed with copper pyrites, and feather copper. The gangue is quartzose, and the value in copper varies from 25 to 45 per cent.

5th Class,—Very rich ores, free from sulphur and deleterious substances. The gangue is quartzose. They contain from 60 to 80 per cent. of copper in the form of native copper, oxide, or carbonate. These choice ores come chiefly from Chili.

The founders also purchase the roasted ores of Chili, and the copper scales and clippings furnished by many workers in copper, also the slags of old furnaces, which still contain a proportion of copper. The fluxes are silica, clay, fluor spar, &c. The last mineral is obtained from the lead mines situated on the banks of the Tamar. The quartz sand, a very large quantity of which is used for the soles of the furnaces, &c., is obtained in abundance on the spot. Fire bricks, for the furnace, are procured from Stourbridge.

That important article in all metallurgic processes, the fuel, is chiefly the anthracite, or stone coal of Wales, which, from the absence of bitumen, produces during combustion little or no gas, and, consequently, very little flame. The value of this coal, compared with the caking varieties, is so small that it will not pay the cost of carriage out of the country, except by way of ballast, as already noticed. Every year about 900,000 tons of anthracite coal are raised in South Wales (in 1857 the quantity was 960,500 tons); and in getting out this coal a nearly equal quantity of small coal is produced. As this dry anthracite coal does not cake by the action of heat, but crumbles to powder, it cannot be converted into coke; it is of no use in the roasting furnaces, as they are usually constructed, because it slips through the bars when added to the fire in moderate quantity, and obstructs the draught, and extinguishes the fire when added in large quantity. The difficulties of using such coal in reverberatory furnaces, such as are employed in Wales in the smelting of copper, have been overcome in a very remarkable and highly ingenious manner, as will be noticed presently.

In the smelting of copper ore, as practised in Wales, there are ten fundamental operations, viz.—1, The Calcination of the ores; 2, Melting for coarse metal, 3, Calcination of coarse metal; 4, Melting for white metal; 5, Melting for blue metal; 6, Re-melting of the slags; 7, Roasting of white metal; 8, Roasting for regule; 9, Roasting; 10, Refining and toughening.

FIRST OPERATION.—All the ores of the first class are roasted, or *calcined* as it is called in Wales, and the operation is conducted in a reverberatory furnace, of which a section and plan are shown in Figs. 615, 616. This calcining is necessary on account of the presence of a large quantity of iron pyrites, which would not allow the ores to be raised in value as respects their copper, by mechanical processes merely, such as are adopted with so much success with the ores of other metals. The presence, also, of arsenical sulphurets indicates the necessity for calcining. The ores are conveyed from the dépôts near the quays, *q q*, Fig. 620, along an inclined plane, I, and are then wheeled to a tram-way, *s s*, Fig. 620, and *t*, Fig. 615, situated over the calcining furnaces, and the charge is thrown into two large hoppers of plate-iron, H H, Fig. 614 and 615: these are closed at the bottom by means of a plate, on withdrawing which the charge falls upon the sole of the furnace *s*, Fig. 616. This sole, which is composed of fire bricks, is 23 feet long, and 23 feet wide. The vault of the furnace descends by a rapid slope from the fire, to C, the entrance of the flue, *f*, Fig. 615. Two sides of the furnace contain each two doors, Fig. 614, which allow the men to spread the charge, and work, or *rabble* it from time to time; a hole, *o*, Fig. 614, situated near the bridge, *b*, admits a quantity of air, which can be regulated by means of a register plate. There are four oblong openings, *h h*, in the sole, closed during the calcination with iron plates, on withdrawing which, the charge can be raked out into the reservoirs, R.

It is necessary in roasting ores that a flame should be produced, and reverberated, or reflected down upon the mineral: this is usually done by burning a bituminous fuel in the grate, and the flame thus produced is reverberated upon the ore by the peculiar form which is given to the vaulted top of this kind of furnace, and also by the draught excited by a tall chimney. But as anthracite does not produce a flame, some contrivance was necessary to apply to the useful purposes of the copper smelter the immense stores of this mineral with which South Wales is supplied. When anthracite is raised to a very high temperature it forms a vitreous scoria, or *clinker*, which, in the ordinary form of furnace, occasions great loss and embarrassment, by choking up the bars of the grate, and combining with the iron of the bars leads to their rapid destruction. In the Welsh furnaces these clinkers are made to perform the office of the bottom bars of an ordinary furnace, supporting the fuel, and limiting the supply of air through the spaces between every two bars. The clinkers themselves are supported on iron bars placed at a considerable distance apart; these do not perform the usual office of the bottom bars, but are merely supports for the clinkers, which are piled up upon them so as to form a layer from 12 to 16 inches thick. Above this support the fuel is in full combustion, and forms the hottest part of the fire, and here it is that fresh clinkers are being continually formed, and in the act of formation they cake with the numerous fragments of small coal heaped up above them. As this new clinker forms, it gradually descends towards the bottom of the fire, and becoming chilled by the rapid current of ascending air which supports the combustion, splits and cracks into numerous fragments. In this way new channels are formed sufficiently large to admit the ascending air in powerful jets, which urge on the combustion, but not large enough to allow the small coal to fall out and escape. The *calciner man*, who has charge of the operation, disengages a few of the bottom clinkers as they accumulate, so as to preserve certain relative proportions between the different parts of the fuel, which experience has found to be best adapted to the successful working of the fire.

The anthracite, which is chiefly used as the fuel, is mixed with about ¼ of its weight of small bituminous coal, which, caking with the anthracite, and swelling up by the heat, preserves in the mass the requisite degree of porosity. The layer of anthracite above the supporting clinkers is about 12 inches thick. The air traverses this layer through a multitude of channels, formed by the cracks in the clinkers: its oxygen is entirely converted into carbonic oxide, and this gas mingled with the nitrogen, streams through the furnace. Under ordinary circumstances the carbon of fuel under combustion is converted into carbonic acid, which is an uninflammable gas, and prevents the combustion of other bodies. Nitrogen, also, will not support combustion. By the above arrangement, however, the carbonic acid, which is formed by the combustion of the fuel, is deprived of a proportion of its oxygen, and is converted into the inflammable carbonic oxide before, or just as it escapes into the vault of the furnace. But its inflammable property would not, under ordinary circumstances, be displayed here, for it is accompanied by nitrogen, which will not support combustion, and the sulphuretted and arseniuretted hydrogen gases liberated by the calcining ore, although combustible themselves, will not support combustion. In order, therefore, to enable the carbonic oxide to burn, it is necessary to supply it with a supporter of combustion, such as the oxygen of the atmosphere; and for this purpose an opening, O, Fig. 616, is made through the wall of the furnace, just above the ore; each of the four doors, two of which are seen in Fig. 614, is also furnished with a small hole, *o*; through these apertures the air streams with considerable force, depending, of course, upon the draught of the chimney, and supplying oxygen to the carbonic oxide, the whole surface of the ore is played upon by a thin sheet of flame, which burns only on its under surface, while its upper surface, or that of the carbonic oxide which supplies it, is in contact with gases which do not support combustion. In this

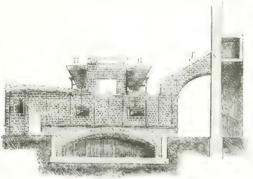
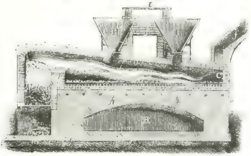


FIG. 614. VIEW OF CALCINING FURNACE.



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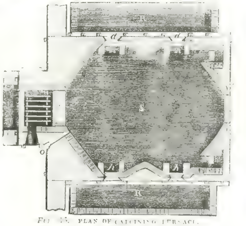

FIG. 616. PLAN OF CALCINING FURNACE.

way the calcination proceeds, and all the gaseous products are, at length, discharged into the chimney by means of the flue, F. The whole of this arrangement is exceedingly beautiful and instructive; indeed, we can scarcely conceive a more difficult problem, especially as the economical calcination of the ore requires the furnaces to be of very large size, and such fuel as anthracite, which burns with scarcely any flame, would seem, at first view, to be the worst that could possibly be chosen for heating large surfaces, and for so moderating the heat as to maintain nearly the same temperature over a surface of nearly 23 feet square; it would naturally be supposed that an excess of temperature would prevail in the region near the fire. All these difficulties, however, are completely resolved by converting the combustible into carbonic oxide, and diffusing this gas over the whole surface of the sole, and then causing it to burn slowly, by admitting a current of air distinct from that which traverses the fire.

Each charge of ore weighs 3.45 tons. It is introduced into the furnace by pulling out the iron plates at the bottom of the hoppers; these are immediately replaced, and the ore is distributed over the sole in a uniform layer by means of long iron rakes, introduced in succession through each of the 4 large doors, Fig. 614. The charge is made up of a mixture of ores, according to the judgment and experience of the smelter. Some of the ores have been dressed and washed; others have been simply crushed, but not powdered; the largest fragments not exceeding the size of a nut. The temperature of the furnace requires to be carefully regulated; if too high, the ore would become pasty, and a superficial glass of sulphur and oxide of iron would form and delay the process. At a properly-graduated temperature the iron pyrites, without ever becoming soft, is decomposed in concentric layers, which allows the oxygen to penetrate through the porous, pliable mass of ferric oxide, which is being constantly formed, and, combining with the sulphur, forms gaseous compounds, which are driven off. The fusion of the ore goes on gradually diminishing as the pyrites loses its proportion of sulphur, which is replaced by metallic oxides. The heat can then be increased without any fear of softening the materials; and when, at the end of 11½ hours, the charge is raked out, the furnace is at its greatest heat. It is not necessary to allow the furnace to cool before putting in a fresh charge, as is done in many other metallurgic operations, because the large mass of ore, 69 cwt., absorbs the excess of temperature. A quarter of an hour after the charge is introduced, the furnace has sunk below a red heat; the moisture of the mineral is rapidly disengaged, and even sulphurous fumes are given off in the vicinity of the fire.

Each furnace is attended by two calciner men, each man working 24 hours alternately. During the 11½ hours of calcination, one man attends to the furnace; but at night, when a new charge is required, two men from two contiguous furnaces assist, so that the furnace may be cooled as little as possible by keeping the doors open. The charge being spread over the sole, the calciner man rests for a short time, and then begins to urge the fire, which, during the previous hour, had become somewhat slackened. He examines the state of the clinkers, and cautiously removes those which prevent the access of air, re-opening with the point of an iron rod the air channels; he next throws upon the fire a charge of coal, and then closes up the fire-door hermetically, by heaping up against it the coal required for the next charge, which is added after an interval of 80 minutes.

An hour after the commencement of the operation, the sulphurets are in full decomposition; this action is, however, confined to the upper portion of the ore, which is directly exposed to the action of the flame, and the oxygen of the atmosphere. This oxidation of the sulphurets disengages a considerable quantity of heat, which favours the operation. Two hours after the commencement of the operation, the calciner man renews the surface of the ore by tracing over the whole extent of the mass a series of parallel furrows. This operation is performed with a long iron rake, called a *rabble*, and the operation itself is termed *rabbling*. It is performed in about 12 minutes the 4 doors of the furnace being opened in succession for the purpose. During the night the calciner men sleep near their respective furnaces, but a watchman goes round every 2 hours to call up the men for the rabbling.

11½ hours after the commencement of the operation the ore is raked out into the reservoirs, RR, Fig. 616. This is a very painful operation, for the ore. having lost only one half of its sulphur, coming in contact with the external air at this high temperature, discharges considerable quantities of sulphurous and sulphuric acids, which become diffused all around, and render respiration almost impossible to persons who have not been accustomed to these deleterious fumes. Indeed, the men themselves suffer greatly; they cover the mouth and nostrils with a handkerchief, and occasionally rush to a distance to inhale a less impure air. A new charge being given to the furnace, the operation is repeated as before.

By comparing the first of the following tables[1] with the second, the changes which have been effected on the ore will be understood.

	Substances Employed.	Absolute Weight	Relative Weight.
Crude Ore.	Oxide of Copper, isolated or combined	3.2	0.004
	Copper pyrites	194.2	0.227
	Iron pyrites, $Fe\ Su_2$	191.9	0.224
	Various sulphurets	8.7	0.010
	Ferric oxide	5.2	0.006
	Various oxides	2.3	0.003
	Quartz and silica	294.4	0.343
	Earthy bases	16.0	0.020
	Water and carbonic acid in combination	4.2	0.005
Atmospheric oxygen		135.0	0.158
		855.1	1.000

	Products.	Absolute Weight	Relative Weight.
Calcined Ore.	Oxide of copper	46.2	0.054
	Copper pyrites	96.0	0.112
	Sulphuret of iron, $Fe_2\ Su_3$	95.8	0.112
	Various sulphurets	5.1	0.006
	Ferric oxide	100.2	0.117
	Various oxides	5.2	0.006
	Sulphuric acid in combination	9.5	0.011
	Quartz and silica	294.4	0.343
	Earthy bases	16.0	0.020
Gaseous products	Sulphurous acid	182.5	0.214
	Water and carbonic acid	4.2	0.005
		855.1	1.000

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[1] The tables contained in this article are from analyses made at Swansea by M. F. le Play, Professeur de Métallurgie à l'Ecole des Mines, and given by him in an elaborate article on the smelting of copper, contained in the "Annales des Mines" for 1848, to which we have been considerably indebted in this article.

The above results may be expressed still more concisely; thus—

Substances Employed.		Products.	
Crude ore	0.842	Roasted ore	0.754
Atmospheric oxygen ...	0.158	Sulphurous acid	0.211
		Water and carbonic acid	0.035
	1.000		1.000

The total annual weight of ores smelted in South Wales amounts to about 200,000 tons, from which about 46,000 tons of sulphur is expelled to waste, and this produces about 92,000 tons of sulphurous and sulphuric acids. Every day the Swansea works project into the air 188 tons of these acid gases, the noxious influence of which extends to a considerable distance: the aspect of the country proves that the fertility of the soil is thereby considerably diminished, especially in the direction of the prevailing winds. The action on animal life, although not so evident, is no less certain. Where the smoke is so diluted by diffusion that grasses can grow, the cattle that feed on them and the sheep pastured on them are subject to luxations and enlargements of the joints, and a metallic coating is given to their teeth. The gases given off from the numerous chimneys of the works form a white cloud, so thick as greatly to diminish the transparency of the air, and when the gases are beaten down by the wind it is sometimes scarcely possible to discern objects a few yards distant. The clouds continue for a long time before they are dissipated in corrosive rain, and they may sometimes be seen after having been driven 3 or 4 miles from the works. Their opacity is probably due to the mutual condensation of the two transparent gases and the aqueous vapour of the atmosphere.

The flues of the various calciners discharge their contents into a gallery, *g*, Fig. 614, where the smoke, being somewhat cooled, deposits some of its solid matter, which, to a certain extent, diminishes the evil. But the smoke of the copper works contains other ingredients besides the principal ones above named. In a tract on this subject, Mr. Vivian gives the following particulars:—"Copper-smoke, or what may be properly considered under that head, as being peculiar to the operations in a copper-work, may be said to consist of the following substances or chemical compounds, formed during the calcining processes by the evolution of substances contained in the ore:—1, Sulphurous acid; 2, sulphuric acid; 3, arsenic; 4, arsenious acid; 5, fluoric compounds, and chemical impurities. Of the above substances, the first two are formed by the combustion of the sulphur. The sulphurous acid, which is by far the most abundant, is evolved in the state of a pungent and penetrating gas. The sulphuric acid, which is composed of sulphur combined with more oxygen than exists in the sulphurous acid, and water, appears as a dense white vapour. The arsenical contents of the copper ores expelled by heat, appear partly as arsenic, in the metallic state, partly as combined with oxygen, forming arsenious acid or white oxide of arsenic: in both cases it assumes the form of vapour. The fluoric compounds are produced by the decomposition of the fluor spar or fluate of lime during the chemical changes occurring in the calcination of the ore. [See Op. II.] The property of fluoric acid to act on silica is well known, and probably if the contents of the flue from the calciner's were accurately examined, silicated fluoric acid gas and hydrofluoric acid would be formed. The mechanical impurities consist of the fine particles of the ore carried over by the draught of the furnaces. They may contain a portion of copper, but the quantity of this is unquestionably very small." In some of the works, lofty stacks have been erected to carry the smoke so high as to become greatly diluted with the air before it reached the ground; but it is stated that the effect of this plan was to increase the evil by diffusing the smoke over a wider area. The plan of passing the smoke through showers of water, as recommended by Sir Humphry Davy and others, has also been abandoned, and it is stated that all the plans hitherto devised for rendering the smoke innocuous, are so expensive, that if adopted it would be impossible to carry on the trade. The prosperity of the town depends so much on the copper-works, that the inhabitants are content to put up with a positive inconvenience rather than by indicting the proprietors, compel them to seek another locality, and take away a trade which has so greatly benefited the town and neighbourhood.

Second Operation.—The object of the second operation is to separate the ore from its gangue, and to get rid of a portion of the oxide of iron which abounds in poor calcined ores. The action of a very high temperature upon the charge is to separate its component parts into three distinct portions: 1, the whole of the copper, or nearly so, is collected in a matt, consisting essentially of sulphuret of copper and sulphuret of iron; 2, a scoria or slag in which the earthy matters, oxide of iron, and other fixed products are collected; 3, gaseous compounds composed essentially of sulphurous acid and other volatile matters, formed by the mutual reaction of the substances employed under a high temperature. The most difficult and also the most important part of this operation is to concentrate all the copper in the matt, for as the scoria which is produced is thrown away as worthless, any portion of copper contained in it is thus lost.

The charge is composed of calcined ore from Op. I., and of some of the scoria rich in copper from Op. IV. V. and VII. which contain substances of easy fusibility, such as silicate of iron, whereby the fusion of the quartz and of the oxide of iron which abound in the ores is greatly promoted, and which, but for this, would react with difficulty on each other. Fluor spar is also added as a flux, and there are also certain earthy matters produced by the action of the charge on the sole and walls of the furnace. The fuel used is a mixture of 0.68 anthracite, and 0.32 of bituminous coal. Each furnace is served by two men, who work 12 hours each: each charge is in the furnace 4 hours, so that 3 charges are made during the 12 hours. The successful working of the furnace depends on the skill and attention of the men, and the older *metal-calciner man* as he is called, is allowed to choose his own mate. The night work is undertaken by each on alternate weeks. The fire is of the same form and dimensions as in Op. I. but it is managed differently. The base of the fire consists of a thick mass of clinker, through which the air streams in powerful jets, and in larger quantity than in Op. I., so as to produce a much higher temperature. A small hole in the furnace door allows the workman to watch the process, and he usually estimates its success by the intensity of the light. If this diminishes, the fire has too much or too little solid fuel upon it, or the gases which issue from it are not in the proper proportion to form the highest attainable temperature. If there be too much fuel on the fire (as would be the case if the charge of fuel were not added after the proper interval, but were heaped up at a later period,) the man rakes out some of the clinker, and thus increases the supply of air. If there be too little fuel, the remedy is to divide the charge of coal into several portions, and to add a portion frequently. A diminution of temperature is fatal to the success of the operation, for the charge under such circumstances becomes fused to the sole, and it requires a considerable outlay of time and fuel to restore the mass to its state of fusion. Indeed, the management of the fire in this operation requires tact and judgment: the supply of air must be carefully regulated, for if in excess, a short flame will be produced, not sufficient to reach to the extremity of the furnace.

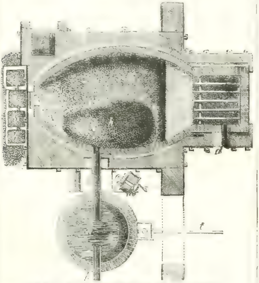

FIG. 617. PLAN OF COARSE-METAL MELTING-FURNACE.

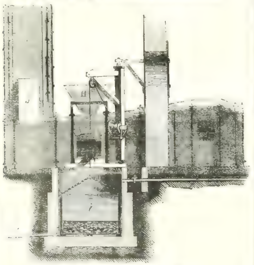

FIG. 618. COARSE-METAL FURNACE.

The interior capacity of the furnace is about 3 times less than that of the calcining furnace, Op. I., nevertheless a very much larger quantity of fuel is consumed. The quantity of coal consumed in 12 hours amounts to 1.677 tons, to burn which requires 1.635 ton of oxygen or 7.106 tons of atmospheric air. The results of the combustion are therefore :—

Combustible gas, produced by the distillation of the coal	0.366
Carbonic oxide	2.861
Nitrogen	5.471
Clinker	0.065
	8.763 tons.

The chimney is of large size, and the gases pour into it at a very high temperature. There is no lateral opening in the flue to cool the current, as at *g*, Fig. 614, and the single opening through which the charge is drawn out, is carefully closed during the operation. A door, at the extremity of the furnace, allows the workmen to elaborate the charge by means of a long rake, and the effect of opening this door is not to cool the furnace, because, although the draught is thereby suspended, yet the cool air rushing in to supply the fire, escapes not into the furnace, but into a side opening. The second charge is introduced immediately after the first is withdrawn; the calcined ore, Op. I., and the flux are poured into the hopper above, and so let down into the furnace; the scoria, which is in large lumps, is thrown in through the door. The composition of the charge varies with the nature of the ores; the scoria from Op. IV. V. and VII. accelerate the fusion, and the metal-calciner men are consequently very eager to get it. This kind of slag has increased in quantity during the last 20 years, in consequence of the importation of the rich foreign ores. The weight of refractory matter in each charge usually varies from 1.05 ton to 1.20 ton, and the weight of scoria assisting the fusion 0.15 to 0.20 ton. The following is an average composition of a charge :—

	Tons.	Tons.	Tons.
Calcined ore	0.856	1.020	1.122
Crude ore	0.164		
Fluoride flux		0.031	
Scoria of the same operation		0.071	
Fusible scoria from Op. IV.		0.106	0.178
,, ,, Op. V.		0.003	
,, ,, Op. VII.		0.069	
Total			1.300

The workman begins by letting fall on the sole 1.051 tons of ore and flux; he then closes the funnel

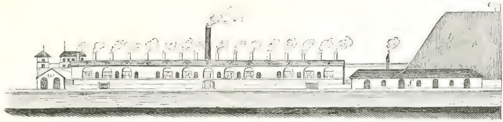

Fig. 619. ELEVATION OF A SWANSEA COPPER WORK.

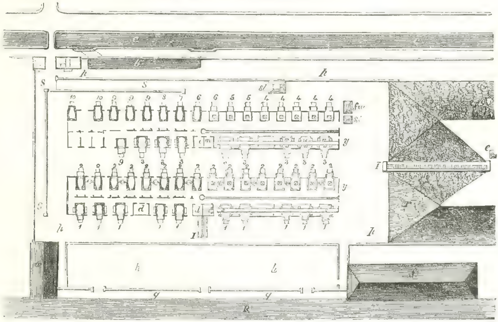

Fig. 620. GROUND-PLAN OF THE SAME.

R	River by which the ores are conveyed.
q q	Landing quays.
h h	Heaps of ore.
I	Inclined plane.
p p	Sloping terrace.
s s	Tram-way over the calcining furnaces, No. 1.
Nos 1—10.	Furnaces employed in the various Operations I to X.
S S	Slopes
w	Warehouse.
f	Rolling-mill.
i i	Depots of ore from Ops. II., IV., & VI.
f w	Heap of furnace-waste.
sl	Heap of slag.
y y	Yards where slags are sorted.
r	Rubbish heaps of slags raised up the inclined plane I by means of the small engine e.
c	Canal by which coals, &c. are brought
b	Canal basin.
p p	Quays for landing Coals, &c.

and the damper of the flue, and by means of a rake rapidly spreads the charge in a uniform layer over the sole. Then taking in his hand the largest pieces of scoria heaped up near the furnace door, he throws them in, scattering them about with tolerable regularity; he then lowers the door, and carefully excludes all access of air thereby by luting it to the wall. The charge is then left for 3½ hours to the influence of the heat, and the man devotes his time to the management of the fire, and the conveyance of the different materials required for the use of the furnace. He detaches from time to time fragments of clinker which fall into the ash-pit, and he keeps open, by means of a pointed iron, the central channel of the fire, which has a tendency to become choked up; a fresh supply of fuel, weighing 0.168 ton, is added about every 72 minutes, and this charge is twice the thickness of the charge in Op. I.

The men of 4 furnaces usually unite in bringing the ore, flux, &c. to the furnaces. It is to the interest of the men, who are paid by the charge, to pass as many charges as possible through the fire within a given time, and if left to themselves, they would take a short supply of the refractory minerals, and lessen the weight of the charge. A foreman is therefore stationed near the weighing-out scales, who makes an entry of every charge.

About half-an-hour after the charge has been introduced, the superficial layer of scoria begins to fuse, and forming liquid furrows among the powdered materials of the charge gradually filters through them, or collects in little ponds. The quantity of fluid silicate rapidly increases, and it soon begins to foam in consequence of the formation of gases below it, and escaping up through it; this agitation brings into more intimate contact the fluid silicate, and the substances which compose the scoria in process of formation, assisting at the same time in reducing it to a fluid state, while the elements of the matt are by the separation of the materials of the slags brought together, and begin in their turn to react upon each other, leading to the production of gaseous compounds. By degrees, the fusion and consequent separation of the slag and of the matt are accomplished, the matt occupying the lower surface of the sole, and the lighter and more bulky scoria floating on its surface. In 3½ hours, the metallurgic reactions appear to have ceased; a few bubbles of gas rise here and there on the surface and burst; around the edge of the sole may also be seen floating foam-like masses which have escaped liquefaction; the man observing these, opens the door and rabbles the charge, detaching these masses, which fall into the fluid scoria and dissolve. The rabbling being completed, the man closes the door, lets fall some clinker, and arranges his fire so as to produce the maximum of heat. He then prepares for the *casting* of the scoriæ or slags, for which purpose he spreads out a quantity of sand, which has been heaped up on the ground before the door, and having levelled its surface, he digs in it 4 rectangular cavities 1, 2, 3, 4, Fig. 617, in which the scoria is received and moulded. The matt is drawn by the channel *p*, Fig. 617, and the slags by the door at *o*. These are allowed to pour out first into No. 1; when this is full it pours over by a side channel into No. 2, and then into No. 3, and when these are full, No. 1 begins to pour into No. 4, by passing over a channel a little more elevated than the others.

A quarter-of-an-hour after the rabbling, the man prepares for the casting of the matt by cautiously tapping with a pointed iron the orifice communicating with the lower part of the sole. A thin stream of liquid matt issues out and falls into a cylindrical iron vessel immersed in a well, w, supplied with cold water by the pipe *t*, the effect of which is to granulate the metal, and to divide it into portions of about the size of hempseeds, the largest not exceeding that of a bean. The man then opens the door of the furnace, and draws out the slags into the mould already described; this part of the process requires considerable care, in order to separate the slags from the matt. The basis of this scoria is a silicate of iron, which in itself is very fusible, but its fluidity is greatly diminished by the presence of several fragments of quartz and quartzose rock entangled with it. It is too viscid to flow out spontaneously, but must be got out by a rake. To prevent it as much as possible from mixing with the matt, the sole *s* of the furnace is so arranged as to incline towards a sort of basin, *h*, Fig. 617, on one side of the furnace, and occupying scarcely ⅓d of the area of the sole. At the end of the operation, the scoria covers the matt only in this basin, in all the other parts it rests on the sole. The scoria nevertheless contains a considerable portion of copper, and it is for the purpose of recovering this copper that the scoria is cast into bricks. The granulated copper having a tendency to fall to the bottom of the mass of slag, it is chiefly collected in the mould, No. 1; the 3 other moulds being supplied by the overflowing of No. 1, contain a very much less quantity of copper. The men mark the bricks of slag in the order in which they were cast. The scoriæ are at a white heat when they are cast, and their temperature is kept up as long as possible, to facilitate the subsidence of the copper; hence, during the casting, iron plates are set up on edge near the moulds to keep off the cool air, and when the casting is complete, the bricks are covered over with sand, In the meantime, the matt continues to flow, its surface in the furnace being protected by the coating of slag, a portion of which has not been disturbed. A certain portion of slag is also left on the sole to protect it from the corrosive action of the slags formed by the next charge, which is introduced while the matt is still flowing off. The volume of fluid matt produced by each charge does not exceed 12 gallons, and the yield of two contiguous furnaces, (Nos. 2, Fig. 620,) is collected into one pit.

With new varieties of ore, the work is a little more laborious, and requires the supervision of the inspector of the foundry; or should the supply of certain ores which are usually employed, fail, the proportions of the charge require modification. In such cases, the flux is not added to the charge at once, and many successive rabblings are required to ascertain the progress of the fusion, the flux is then added as occasion requires. In this way, much practical knowledge is gained which contributes greatly to the success of the work.

The metallurgic re-actions in OP. II. are simple. The oxides and sulphurets are combined in the charge in such proportions that the oxygen lost by the oxides whose metals pass into the matt, and the oxygen lost by the ferric oxide which passes in the shape of ferrous oxide into the scoria, combine with the sulphur of the sulphurets, and form sulphurous acid, the disengagement of which keeps up a certain agitation which favours greatly the progress of the re-actions. The action of the fluoride of calcium, or fluor spar, is somewhat complex. In the gangue of the copper ores alumina and magnesia are more common than lime; the portion of calcium, which, under the influence of oxygen and silica, passes into the state of lime, contributes to the fluidity of the silicates. About one half of the fluor spar remains undecomposed, and the fluor silicate which is formed, adds to the fluidity of the scoria. The fluoride of calcium, which is at first dissolved rapidly in the silicates, for which it has a great affinity, is then decomposed gradually under the influence of the fragments of silica suspended in the mass; the silica yields oxygen to the calcium, and the resulting silicum, which is the exact equivalent of the fluorine of the fluor spar, combines therewith. This disengagement of fluoride of silicum forms a sort of natural rabbling of the charge at the period when sulphurous acid is no longer disengaged, and this mechanical action is one of the essential advantages of the fluor spar flux.

The following statement will show the results of Op. II.—

SUBSTANCES EMPLOYED.	
Calcined ore	0.724
Crude ore	0.084
Poor scoria, from Op. IV.	0.085
,, ,, V.	0.051
,, ,, VII.	0.008
Fluoride of calcium	0.041
Earthy matters.—sand	0.001
,, ,, brick	0.006
	1.000

PRODUCTS.	
Coarse metal, for Op. III.	0.275
Scoria	0.670
Furnace waste, from Op. IV.	0.009
Sulphurous acid	0.035
Sublimed sulphur	0.001
Fluoride of silicium	0.008
Water and carbonic acid	0.002
	1.000

An examination of the scoria produced in Op. II. will always show whether the metal calciner men have done their duty. The scoria are inspected in a court-yard, *y y*, Fig. 620, where the men deposit it in regular order, under the number of each furnace. Each brick is broken with a hammer, and the fracture examined; the lower part of the brick is minutely inspected, especially that of the brick No. 1: the small grains of matt, mechanically mixed with the slag, exhibit a clear bronze colour, and a metallic lustre on the black, dull surface of the fracture. The value of the copper in the slags is thus judged of very accurately: if the proportion be from $\frac{8}{1000}$ to $\frac{12}{1000}$ an experienced eye can tell within $\frac{1}{1000}$ or $\frac{2}{1000}$ the quantity of copper contained therein. In breaking up the bricks the inspector forms the fragments into two heaps; the larger heap contains those which are to be thrown upon the rubbish heap, *r*, Fig. 620, the other heap contains those fragments which are to be returned to the furnace. Each new charge contains 0.071 tons of this rich scoria; a larger proportion than this would be injurious, but as a larger quantity than can be used is produced, the surplus is melted down once a-week or fortnight, for which service the men receive no pay.

The iron cylinder containing the *coarse metal*, as it is called, produced by two contiguous furnaces, is hauled up by means of a crane, Fig. 618, and conveyed in wheelbarrows to the dépôt, Fig. 620.

Sunday is to the men engaged in Op. I. and II., what it ought to be to every one, a day of rest from worldly occupation. The fires, however, require to be kept up, and this service is performed by one man, who has the charge of 4 furnaces, and he must so arrange that the furnaces be at the full heat for the reception of the charges on Monday morning at 5 o'clock.

THIRD OPERATION.—The coarse metal obtained in the last operation is in very small fragments, externally of a deep brown colour; they are easily crushed by a blow, and the surface of the fracture is of a brownish red. The metallic copper forms about $\frac{1}{3}$d of the total weight; it is, in fact, very similar to copper pyrites free from gangue. It is, therefore, in the first part of Op. III. simply calcined with access of atmospheric air. The charge is weighed out, and conveyed in wheelbarrows to the hoppers over the calcining furnaces, which are similar to those used in Op. I. Each of these is served by two men, who relieve each other alternately. One man must work on Sunday, because each operation extends over a period of 36 hours.

The most important part of this operation consists in the management of the fire; it is the same in principle as in Op. I., but more fuel is consumed, and the heat requires to be greatly increased towards the end of the operation; 0.043 tons of coal per hour is burnt, whereas in Op. I. it was only 0.035 tons. The charge having been spread over the sole, the temperature is kept up to the highest that it will bear without fusing. Two hours after the doors have been closed it emits abundant fumes of sulphurous acid, and it is rabbled every two hours in order to expose a fresh surface. The charge must be gradually raised during the first 12 hours to an incipient red heat; by the 24th hour the charge and the walls of the furnace must be at a cherry-red heat, and by the 36th hour at a lively red. The effect of rabbling is not only to expose new surfaces, but also to break up any masses which tend to agglutinate.

The coarse metal is the only solid product of this operation; the sulphur passes off in the form of sulphurous and sulphuric acids, while a proportion of oxygen combines with the matt nearly equal to that of the sulphur expelled. Omitting the sulphuric acid, the following tables will show the difference between the substances before and after the operation:—

SUBSTANCES EMPLOYED.		
Coarse metal		0.804
Oxygen of the atmosphere		0.196
		1.000

PRODUCTS.		
Calcined coarse metal, for Op. IV.	0.566	0.783
,, ,, ,, V.	0.217	
Sulphurous acid		0.217
		1.000

The product of this operation may be bad either from the result of too high or too low a temperature. There is not much chance of too high a temperature being produced, for this would agglutinate the charge, and give the workman much extra labour in rabbling. The danger is the other way, and in order to keep the men to their work 4 inspectors are appointed to 15 furnaces, whose duty it is to see that the heat is gradually and properly raised, and that the rabblings are attended to every two hours.

The physical and chemical properties of the coarse metal are greatly altered by calcination: the fragments are much reduced in size, the general colour is a deep black, with light brown reflections; many of the grains are friable; others are encased in a friable envelope, the nucleus being hard and compact; this, when broken, has a lustre of various colours; other fragments are formed by the incipient fusion of several particles together.

FOURTH OPERATION.—*White metal*, the object of this operation, is produced by associating with the calcined coarse metal those ores of copper which are almost entirely free from sulphuret of iron, and consist principally of sulphuret of copper, oxide of copper, and quartz, in such proportions that the sulphuret of iron becomes oxidized at the expense of the oxygen of the oxides. The excess of sulphur, or that which is not acidified in this operation, combines with the whole of the copper, forming white metal, (which, in its purest state, is the disulphuret $Cu_2 S$,) while the oxide of iron, combined with silica, passes entirely into the slag. In practice, however, these reactions cannot be accomplished with the precision which theory indicates, because it is impossible to bring the oxides and the sulphurets together in true chemical proportions. The reaction is made as complete as possible by prolonging the operation, and the most advantageous result is found to be obtained by leaving a certain portion of iron in the matt, and a considerable portion of oxide of copper in the slag. This enriching of the slag does not produce any inconvenience, for none of it is thrown away, as in Op. II.; on the contrary, it is of considerable value in a subsequent operation. By continuing to enrich the slag the last traces of sulphuret of iron are expelled, and pure white metal is produced. There is, however, danger of exceeding this limit, in which case the oxides in excess act on the sulphuret of copper, and reduce a portion of it; the metallic copper produced under these circumstances is always of inferior quality. Indeed, the principle of the operation of melting for white metal is to avoid as much as possible this reduction of copper, and to attain this end there must usually be left from 4 to 8 per cent. of iron in the matt, and from 3 to 5 per cent. of copper in the slag.

The materials employed in this operation are rather numerous. The calcined coarse metal forms one half the charge: then a proportion of rich foreign ore in the crude state: slags from Op. IX. and X., composed essentially of silica and oxide of copper: furnace waste from all the operations: different copper wastes from the workers in copper, such as scales produced during the lamination of copper: lastly, silica, &c. from the sole and walls of the furnace in which the operation is conducted.

The furnace employed in this operation, No. 4, is similar to that used in Op. II. Fig. 617, but there is no depression in the sole; its whole surface slopes very gradually, just sufficient to allow the escape of all the fused substances towards the orifice of the discharge-pipe, situated on one of the long sides, as at *o*, Fig. 617.

The men entrusted with the charge of the furnace belong to a superior class: they are expected to watch the process narrowly, and to vary the succeeding charge according to the indications of the preceding one; there is no means of exercising a complete control over them, on account of the variable nature of the charge, and especially of the rich foreign ores. The fire is managed as in Op. II. only more coal is burnt. The charge remains six hours in the furnace, and is raised to the most dazzling white heat. The charge weighs ordinarily about 1.6 ton; but this varies; the object being to associate, in proportions as constant as possible, the copper and the sulphur, which after the mutual reaction of the sulphurets and oxides ought to form essentially the matt, and the silica and the oxide of iron, which ought to form the scoria.

The calcined ore, the rich foreign ores, copper scales, &c., are introduced through the hopper and then spread over the sole; the remaining portion of the charge is introduced through the door, and distributed by means of a tool made like a baker's peel. The doors are then carefully luted; the substances calcine rapidly at the surface without entering into fusion: in an hour's time there is a softening, which is made evident by the escaping gases: in 3 hours, a portion of the charge is floating in another portion which has become fused: the surface is not disturbed by the escape of gas. At the 4th hour the masses are detached from the sides and broken up by rabbling. At this time the scoria is very fluid, and on urging the heat all the matters appear in complete fusion and the surface is tranquil. Thus, the first three hours of the operation the fusion of the charge is going on, and during the last three hours the refining of the matt; but during both periods a portion of the more infusible matters are fusing and refining. About 10 minutes before the expiration of the 6 hours, the man pierces the hardened sand at the side of the furnace; the liquid matt flows out and is granulated by being received into water, or cast into pigs by being received into sand moulds: the scoria then flows out in a very fluid state and is also moulded. This scoria contains a considerable portion of copper: it is sorted into two lots of unequal value; the richest portion is that which was in contact with the matt, where oxide of copper prevails; the poorer part consists of the upper layers, where sulphur prevails: the former are treated in a special operation, No. VI; the latter are useful in Op. II. in which they act as a flux, and give up all their copper to the coarse metal.

The following tables will show the results of this operation:—

SUBSTANCES EMPLOYED.

Calcined coarse metal, Op. III	0.559
Crude ores	0.243
Copper scale, &c.	0.007
Scoria from roasting, Op. IX	0.060
,, ,, refining, Op. X.	0.024
Furnace waste, Op. II. and IV. to X	0.060
Earthy matters.—sand	0.041
,, ,, bricks	0.006
	1.000

PRODUCTS.

White metal, for Op. IX	0.402
Poor scoria, for Op. II.	0.261
Rich ditto for Op. VI	0.281
Furnace waste, for Op. IV.	0.009
Sulphurous acid	0.043
Water and carbonic acid	0.004
	1.000

The white metal is conveyed to the furnace for Op. IX: the scoria is removed to the dépôts *y*, *y*, Fig. 620, where it is broken up. Each furnace elaborates 22 charges per week.

The white metal in its purest form has a very clear greyish white colour: it has a granulated texture, and is full of numerous small cavities: its sp. gr. is

5.70. Another form of this metal has a bluish or black grey colour, with violet and reddish reflexions: its sp. gr. is 5.32. The usual product is something intermediate between these two varieties, and consists, in 1,000 parts, of copper 0.732, iron 0.063, and sulphur 0.205. It is, in fact, nearly identical with the sulphuret of copper of the mineralogists.

FIFTH OPERATION.—This operation is in many respects analogous to No. IV., its object as well as that of Op. VII. and VIII. being the production of a matt of a richer and purer quality than is usually produced by Op. IV.

It has been found by experience, that when native and foreign ores are subjected to the same treatment, a copper is produced either of medium quality or distinguished by certain good or bad properties. The ores which yield a superior copper are generally worked alone, expressly for Op. V.: the ores of ordinary value pass through the first four operations already described; and the ores of very inferior quality are kept quite distinct, and are worked in furnaces appropriated to the purpose. From the combination of the products of these ores, and from the blending of richer and poorer ores at certain stages, the different varieties of copper known in commerce are produced. The calcined coarse metal used in Op. V. is sometimes that which has been produced from picked ores; at other times it is identical with that ordinarily used in Op. IV.; but in all cases a certain proportion of calcined ore is used as produced from the best copper pyrites. No crude ore is added to the charge, nor is any flux given except that which arises from the sole and walls of the furnace in which the operation is conducted. The following statement will show the nature of the charge and the results of the operation:—

SUBSTANCES EMPLOYED.

Calcined coarse metal, Op. III.	0.722
Calcined ore	0.185
Earthy matters.—sand	0.084
,, ,, bricks	0.009
	1.000

PRODUCTS.

Blue metal, for Op. VII.	0.495
Scoria, for Op. II.	0.434
Furnace waste, for Op. IV.	0.008
Sulphurous acid	0.056
Oxygen	0.007
	1.000

The charge in Op. V. is richer in metallic sulphurets, and contains fewer metallic oxides, than in the charge for Op. IV., so that the result of Op. V. is a matt more charged with sulphur and iron than the ordinary white metal. Blue metal is distinguished by a fresh fracture, a deep grey colour, but at temperatures below redness it assumes beautiful shades of blue, which give a name to the metal. It is more compact than white metal, but its cavities are larger.

The reactions are similar to those of Op. IV. The first action of the heat is to fuse the sulphurets, and to produce a partial reaction on the oxides. The oxide of copper reacts by its oxygen on the sulphur, and on the iron of the sulphurets, producing sulphurous acid, which is disengaged, and ferrous oxide which combines with the silica. The copper thus set free unites with the matt, which is thus doubly enriched by the addition of copper and the removal of sulphuret of iron. While this reaction is going on in substances which are very refractory, a silicate more or less charged with oxide of copper, begins in its turn to liquify and to perform its useful office of refining the matt; the oxide of copper of the silicate and the sulphuret of iron of the matt, mutually react upon each other, and produce, without any disengagement of gas, sulphuret of copper, which enriches the matt, and peroxide of iron (Fe_2O_3) which passes into the scoria.

Metallic copper, which is only accidental in white metal, is characteristic of blue metal. It is disseminated through the compact mass in exceedingly fine particles, which are visible with the assistance of a lens, and there are also occasionally larger particles visible to the unassisted eye. Silky iridescent filaments are also sometimes produced. If the charge has not been properly selected or well managed, there forms below the matt, and at its expense, a certain quantity of black copper, called from its position *bottoms:* this will be noticed again.

SIXTH OPERATION.—The copper produced by the remelting of the slags, formed in Op. IV. VII. and VIII. is of excellent quality, and is known in commerce as *best-selected.* The object of this operation is to make this copper pass into the matt, which is always richer than the blue metal of Op. V.; this object is effected by the mutual reaction of the oxide of copper of the slags, and of certain very pure sulphurets of copper and of iron existing in certain varieties of ore. The reaction is assisted by the addition of small coal to the charge, which effects the reduction of a portion of the oxide of copper, and the metallic copper thus revived traverses the scoria and the matt, and forms into two distinct layers, the lower one consisting of a very impure black copper or *bottoms,* the upper of a white alloy of copper and tin, called *hard metal.*

The charge usually consists of an ore (copper pyrites) free from injurious substances, abounding in quartz, but too poor for Op. V., after being calcined. The exclusion of substances containing sulphur is more attended to than in Op. IV. and V., and hence the sole of the furnace is more exposed to corrosion, especially at the edges of the sole near the walls. This is partially remedied by heaping the charge around the circumference of the sole, which is thus better protected, and when the sulphurets have fused, the quartz of the ore furnishes to the scoria the silica, which would otherwise be taken up from the sole. The furnace is similar to that used in the previous operation, but the external arrangements are different; there is no hopper, but the charge is inserted through an opening on one of the long sides, either by means of the peel or by hand. This opening is closed, and the door luted during the working.

The following tables will show the nature of the operation:—

SUBSTANCES EMPLOYED.	
Rich slag, from Op. IV.	[illegible]
" " VII	[illegible]
" " VIII.	0·053
Copper pyrites	0·079
Sweepings of the foundries, Ops. VIII. IX. X.	0.055
Carbon, employed as reagent	[illegible]
Earthy matters—sand	[illegible]
" " brick	[illegible]
	1·000

PRODUCTS.	
White Metal for Op. VIII	[illegible]
Red metal, for Op. VIII	[illegible]
Tin alloy	[illegible]
Copper bottoms for Op. IX.	[illegible]
Slag, to be rejected	[illegible]
Refuse of furnace, for Op. IV.	[illegible]
[illegible]	[illegible]
Gaseous sulphur	[illegible]
Water and carbonic acid of the ore	[illegible]
	1·000

The white metal thus produced is similar to that of Op. IV., the red metal resembles the blue of Op. V. but differs in the absence of metallic copper; it is also richer in copper and more compact. The alloy of copper and tin (*hard metal*) is hard and brittle, and of a fine tin white colour. It contains minute portions of iron, nickel, cobalt, arsenic, and a trace of sulphur. It is sold to the manufacturers of copper sheathing, its chief use being for the bronze nails used in fixing sheathing.

In Op. VI., the principle is first to reduce the oxide of copper combined with the slags, and to make it pass into the matt, by the double influence of a large quantity of sulphuret of iron, combined with the matt as in Op. IV. and V., and of a trace of sulphuret of iron combined with the silica of the slag as in Op. II., and in the second place, to refine the matt produced, by removing from it, by the influence of the metallic copper and tin, substances which are particularly injurious to the quality of the copper, such as arsenic, nickel, and cobalt. The metals disengaged from the silica, and placed beyond the action of the sulphurets, absorb these injurious substances, which would otherwise have remained in the matt. The metals thus reduced by the direct action of carbon on the oxides of the silicates cannot combine with the matt, for in this, the iron and the copper are saturated with sulphur. The addition of carbon, therefore, produces a quantity of copper and of tin in a minutely divided state, which passes through the matt and collects at the bottom. This action has also a beneficial influence in purifying the matt; the sulphurets of arsenic, nickel, and cobalt, having a strong tendency to yield their bases to the copper and tin, and their sulphur to the elements of the matt, decompose slowly under this influence, and form alloys, which fall to the bottom, and according to the period of the operation produce either sulphuret of copper, which remains in the matt, or sulphuret of iron, which combines partly with the silicates of the slag.

SEVENTH OPERATION.—The object of this operation is to convert the blue metal into white metal, and to expel more completely the substances which interfere with the purity of the copper. This is accomplished by two successive reactions,—1, A slow calcination at a moderate heat, in which, under the direct influence of the air, the principal part of those substances which injure the copper, and a large proportion of the copper itself, are oxidised; 2, fusion, at a high temperature, in which the oxides having been scorified by means of silica, that portion of the matt which was not decomposed during the first period, is refined by the reaction of the oxide in the scoria upon the sulphuret of iron in the matt. This reaction is similar to that which takes place in the second periods of Op. IV. and V.; but the reaction of the oxygen in the first part of the process is distinct from any that has yet been considered.

Blue metal is the only form of copper used in this operation, but its surface is impregnated with sand obtained in casting, which is of use in the process, as is also the furnace waste and the refractory clay introduced every now and then to lessen the corrosive action of the slag; this sand, brick-dust, and clay, reacting on the oxides, produce the scoria necessary to the refining of the matt. 2 tons of blue metal make a charge, and the operation lasts nearly 12 hours. In the first part of the operation, the sole must be cool, so that ¾ hour elapse between the drawing of one charge, and the putting in of another. The blue metal must be put in in very large pieces, and as it is very brittle, each piece is put in by means of a peel worked by 4 persons; the operation somewhat resembles that by which the baker fills his oven with bread. The arrangement of the blocks in the furnace is important; none must be nearer than 3 or 4 feet to the bridge, and spaces must be left between them for the free circulation of the gaseous currents.

The two doors by which the charge is inserted being closed and well luted, the register is opened, and the temperature raised quickly to a dull red; the blocks, under the action of the heat and the oxygen of the air, then fuse slowly, and in the course of 8¼ hours, the whole of the charge is in a semifluid state. The heat is then urged for the second part of the process, and in about 2½ hours it is complete, and the matt and the scoria are cast in a trench in the sand. The following is the statement of this operation:—

SUBSTANCES EMPLOYED.	
Blue metal, from Op. V.	[illegible]
Furnace waste, &c.—sand	[illegible]
" " clay and brick	[illegible]
Oxygen of the atmosphere	[illegible]
	1·000

PRODUCTS.	
White metal for Op. VIII	[illegible]
Poor slag, for Op. II.	0·163
Rich slag, for Op. VI.	0·177
Furnace waste, for Op. IV.	[illegible]
Sulphurous acid	0·124
	1·000

EIGHTH OPERATION.—The products of Op. VI. and VII. are further purified by this operation, which consists (1) of calcining the white metal at a low heat, under the influence of atmospheric oxygen; (2) refining the metal under the slag. But as iron and other extraneous metals exist only in small quantity in the white metal, a comparatively large proportion of oxide of copper is formed during (1), so that in (2) the slag is rich in oxide of copper. Hence the refining due to the mutual action of the metal and of the slag is soon accomplished. The oxide of copper formed in (1) being in excess, reacts on the liquid metal under the higher temperature of (2), whence results sulphurous acid, which is disengaged, and metallic copper; this is precipitated to the bottom and removes from the matt the noxious metals which may be still contained in it. The following statement will show the result of this operation:—

SUBSTANCES EMPLOYED.

White metal of Op. VII.	0.712
Ditto VI.	0.125
Red ,, VI.	0.034
Earthy matters from the sole	0.041
,, ,, brick and clay	0.007
Oxygen from the atmosphere	0.081
	1.000

PRODUCTS.

Regulus of metal VII. for Op. IX.	0.528
,, of metal VI. for ditto	0.112
Coppery bases from VII for ditto	0.088
Ditto ,, VI. ditto	0.020
Slags, to be used again in Op. VI	0.118
Furnace waste, ditto ,, IV	0.004
Copper sweepings, for VI.	0.002
Sulphurous acid	0.128
	1.000

This operation furnishes 3 products: 1, a slag; 2, a matt or regulus very rich in copper; 3, bottoms. The slag consists almost entirely of silica, oxide of iron, and copper. It also contains about 0.11 copper of the matt mechanically mixed. The regulus is the sulphuret of copper, mechanically mixed with metallic copper. It is of a fine metallic grey colour; it is porous, with large cavities coated with a very thin pellicle of copper, the lustre of which varies from tin white to intense red with blue shades. The regulus contains copper 0.811, iron 0.002, sulphur 0.185. The copper bottoms are formed in small plates or scales of a clear but dull red colour, and impregnated at the surface with matt and sand.

NINTH OPERATION.—The complex series of operations thus far described has led to the formation of various products; such as the white metal of Op. IV., the blue metal Op. V., the matt from the remelting of the slags Op. VI., the white metal of Op. VII., the regulus of VIII., the copper bottoms of Op. VIII. and VI. All these products now converge into Op. IX., so that with the exception of the tin alloy, Op. VI., no saleable product has yet been produced. The object is now to expel the sulphur, which up to this period has performed the useful office of a medium, in which to collect, combine, and concentrate the copper as it becomes gradually freed from its other impurities. There is still a minute portion of arsenic, iron, tin, nickel, cobalt, &c. which have resisted the action of Op. IV. to VIII. These are got rid of in the slag. There are two successive reactions in this operation, (1) the direct action of the air on the matt, while at a heat near its fusing point, (2) the reaction of the oxide of copper, formed in great excess on the sulphurets not decomposed. The two products of the operations are coarse copper almost refined, and a slag rich in copper, which is sent to Op. IV.

In this operation there are 4 steps: (1,) calcining, which produces sulphurous acid and oxides; (2,) (3,) the reaction of oxide of copper on the sulphurets which have not been decomposed; (4,) the production of metallic copper, which collects at the bottom of the sole, while the oxides in excess unite with the silica into a slag which occupies the upper part of the whole.

The charge varies from 2.75 to 3.75 tons; the only reagents employed are atmospheric oxygen, furnace waste, and the quartz of certain rich ores, added to the charge. The time required for this operation is 24 hours. About an hour is occupied in putting in the charge, which is in large blocks; the temperature is then raised to the proper calcining heat. After this, the charge is fused, and the sulphurets and oxides becoming mingled together, react on each other, and the surface of the mass is agitated by the escape of gas. It is now important to keep up this reaction as long as possible, in order to promote the decomposition of the sulphurets and thus get rid of the sulphur; this is done by diminishing the temperature, and this cooling of the furnace, which constitutes the second part of the process, is effected by opening the furnace door; the temperature then sinks from a lively red to an obscure heat, sufficient for the mutual reaction of the oxides and sulphurets, but not sufficient for the union of the oxides and silica to form slag, the production of which is not desirable. The mechanical mixture of the materials, which is indispensable to the reaction of the semi-fluid matters, is effected in a curious manner. The effect of cooling the furnace is, of course, first felt on the surface of the fused mass: this becomes more and more pasty, until a point is attained when the sulphurous acid gas, escaping from all points, cannot traverse the viscous mass; it is, therefore, imprisoned within it, and, accumulating, forms large swellings and risings, which not only increase the surfaces, but bring the particles into contact much more effectually than would be done by a continual rabbling. The whole mass thus becomes extremely porous, and being a very bad conductor of heat, the temperature is preserved by the crust, and the reactions necessary to the operation do not cease for a single moment. All the workman has to do is to add a little fuel occasionally, and to regulate the draught. At 6 P.M., or 12 hours after the commencement of the operation, the temperature being considerably diminished, the sulphurous acid ceases to be discharged, which is a sure sign that the oxides of copper and the sulphurets no longer react upon each other. It now becomes necessary to raise the heat, and this is the characteristic of the third part of the process. Six hours are occupied in raising the temperature to the point that it had at the end of the first part of the process. All the doors being closed, the upper crust or scoria now liquefies as gradually as it was formed during (2); and the two reactions which were characteristic of (1,) (2,) are reproduced simultaneously up to a certain point.

At midnight, or 18 hours after the commencement of the operation, the charge contains only a very small proportion of sulphur: all that is now required is to separate the copper from the oxides, which up to this time were mechanically mixed with it, and this is done by scorifying the oxides by means of silica. The heat is, therefore, got up to the highest, in order to combine the oxides and the silica into a slag. Under this great heat the copper becomes completely fluid, and collects at the bottom of the mass, while the slag rises to the surface. At 5.45 A.M. the slag is skimmed off and the copper is cast into pigs in the sand. The men then proceed to a new charge. The results of this operation are shown in the following tables:—

SUBSTANCES EMPLOYED.

White metal, from Op. IV.	0.577
Regulus, from Op. VIII	0.171
Copper bottoms, from VI and VIII.	0.034
Very rich ore	0.035
Earthy matters—sand	0.016
,, ,, bricks and clay	0.008
Oxygen of the atmosphere...	0.159
	1.000

PRODUCTS.

Coarse copper, from the white metal	[illegible]
Ditto from the reguluses	0.143
Ditto from bottoms	0.060
Slag, for Op. IV.	0.087
Furnace waste, for Op. IV.	0.017
Copper sweepings, for Op. VI	0.031
Carbonic acid and water of the ore	[illegible]
Sulphurous acid	[illegible]
	1.000

The coarse copper, the chief product of this operation, is run into pigs, each about 3 feet long and 18 inches wide: they are usually impregnated on one face with the sand of the trough; they are full of cavities of various sizes, and the surface appears as if blistered; hence the term *blistered copper* applied to it. The fresh fracture exhibits a deep red colour, and the inner surfaces of the cavities present brown or yellow reflexions.

The scoria differs in appearance from all the previous slags: it contains more silica; it is of a brownish black colour, without metallic lustre; it is full of little cavities, and resists the hammer as much as certain basaltic lavas, which it in some respects resembles. It contains a quantity of copper in fine grains, and here and there some tolerably large fragments.

TENTH OPERATION.—The object of this operation is to separate all the remaining impurities from the copper, and to impart to it that soft and malleable property which allows of its being worked by the hammer and the rollers. All the coarse copper produced in any of the previous operations now comes into this last one, and the only reagents are atmospheric oxygen, and the waste of the furnace in which the operation is conducted. Towards the end of the operation, however, charcoal and green wood are used. The furnaces employed are of large size, the charge weighing as much as 7 tons, and entirely filling the body of the furnace.

As soon as one charge is disposed of, the furnace is examined, and the parts near the walls and the soles which require it, are stopped with refractory clay; the sole is then raked over, and the charge put in, the pigs being placed one at a time on the peel. All the doors being carefully luted, the man has nothing to do for 18 hours but to attend to the fire, and for this purpose one man has the charge of two fires. Under the influence of the two gases which form the flame, the copper fuses, and a portion becomes oxidized by the in-rushing draught; this oxide reacts either directly, or after having united with the silica, on those substances in the copper which are more oxidisable than the copper itself; and in this way a slag is gradually formed, which contains, in addition to oxide of copper, the oxides of all the metals which were still left in the coarse copper. About 21¾ hours after the commencement of the operation the copper is as free from sulphur, arsenic, &c., as the nature of the metal operated on will allow. The work of the refiner now properly begins, and the charges are regulated so that the copper may be in that state when the refiner and the other people concerned in the operation begin their day's work. The first thing that is now done is to skim off the slag from the surface of the metal. The copper is now in that state which is called *dry;* it is brittle, of a deep red colour, inclining to purple, of an open grain, and crystalline structure. In this state it has a strong action on iron; the tools employed in removing the slag, &c., wear away more rapidly at this time than when the copper is in its malleable state. The copper is made tough or malleable by the action of carbon and combustible matter on the copper during a short period only, for it has been found by experience that the property of malleability is produced after a certain contact with the carbon and the metal, and becomes considerably weakened if prolonged only for a few minutes, and destroyed if the action is continued. It may, however, be restored by leaving the copper exposed to the oxidising influence of the air.

When the bath has been skimmed, 4 or 5 peels-full of charcoal are thrown upon it; the charcoal spreads immediately over the fluid metal, and covers it almost completely. Some very pure Welsh anthracite can generally be used instead of the charcoal, which is only used in refining some of the very best sorts of copper. When the bath is thus covered with carbon, a tolerably stout pole of green wood is plunged into the midst of the metallic mass; the juices of the wood are immediately disengaged in a gaseous and vaporous form, which causes the fluid metal to bubble up, and foam with great violence, an operation which greatly accelerates the effect which the charcoal would produce in the course of time.

During all this time the draught is considerably diminished, and the air which feeds the fire passes up and escapes by an opening above, without entering the furnace; hence the metal, not being cooled by the air rushing in, retains its high temperature, and the scoria, which had attached itself to the sides of the vault, falls down in drops, and contributes to increase the new layer of scoria which is forming on the surface of the metal. In the meantime the strong effervescence is kept up on the metal from 15 to 25 minutes, until the refiner has detected the exact moment when the metal has attained its maximum of malleability. This is done by making an assay in the following manner:—Having exposed a small portion of the surface of the metal 3 or 4 feet beyond the door, the man introduces an ingot mould attached to the extremity of a long iron rod, and quickly catches up a small portion of copper. This ingot is then cut half through by means of shears, and broken in two by means of a hammer. The surfaces of the cut and of the fracture vary with different varieties of copper, and enable the assayer to judge of the malleability of the specimen in hand. But for any particular variety of copper the character of the fracture may vary in every ingot taken out, and all these differences have an intelligent meaning to the practised eye of the assayer. If the action of the charcoal has not been sufficiently prolonged, the first ingots taken out will exhibit a dull, granular fracture, of a deep brick red colour, with scarcely any metallic lustre. In the succeeding specimens the structure passes insensibly into the fibrous, the fibres being exceedingly minute and of a silky lustre; the colour is also of a pale red, the characteristic of rose copper. Beyond this type the texture becomes coarser, the fibres increase in size, and their fracture exhibits striæ; the lustre, without losing its metallic brilliancy, ceases to be silky; the colour becomes paler, and a yellow shade is very decided. If after this the surface of the bath be left to the action of the oxygen of the air, the characters of the metal change in an inverse order. The two extremes of grainy and fibrous represent coppers which are not adapted to any mechanical processes; but the maximum of malleability corresponds to the most silky texture. This type being attained, the bath is once more skimmed, to remove the charcoal and a thin layer of slag; a little fresh charcoal is then thrown over the surface, a quantity of fuel is thrown upon the fire to produce a quantity of combustible gas, which is admitted into the furnace; and then the casting is proceeded with. The copper is taken out in iron ladles coated with clay, and is poured into moulds adapted to the wants of the manufacturer. The usual size of the cakes for common purposes is 12 by 18 inches. Although a number of men are engaged in the casting, it generally lasts 1½ hour. During this time the copper is kept in as uniform a state as possible, and it is repeatedly watched by taking assays out of the ladles. The charcoal which covers the surface of the bath acts in a manner the reverse of that of the oxygen of the air, and under these opposing influences the metal ought to remain in a state of equilibrium throughout the casting. The assays detect any deterioration either towards the granular or the fibrous structure, and, according as one or other occurs, charcoal is added, or taken away. The following statement shows the result of this operation:—

MATERIALS EMPLOYED.

Coarse copper	0.954
Earthy matters.—sand	0.013
,, ,, brick and clay	0.021
Oxygen of the air	0.012
	1.000

PRODUCTS.

Saleable copper	0.908
Slag, for Op. IV.	0.065
Furnace waste, for Op. IV.	0.012
Copper sweepings, for Op. VI.	0.002
Sulphurous acid	0.013
	1.000

The varieties of copper which are sent into the market are produced by varying the ores, the proportions of the charge, and the treatment. Among these varieties the following six may be mentioned, with the prices in 1848:—

		£	s.
First Quality...	*Best selected copper*, from slag of resmelting	98	0
Second Quality,	*Best selected copper*, from the resmelting (extra process)	97	5
Third Quality..	*Tough copper*, for exportation. Copper of ordinary manufacture, mixed with one third of best selected (second quality)	96	0
Fourth Quality,	*Tough copper*. Copper of ordinary manufacture, from common ores	95	2
Fifth Quality...	*Tile copper*. Of ordinary manufacture, from ores loaded with foreign matters	94	0
Sixth Quality .	*Tile copper*. Manufactured from bottoms, Op. VI. and VIII.	93	5

The first two qualities are almost chemically pure copper: they contain the merest trace of those substances which so greatly injure the valuable properties of copper. The other qualities contain about 0.008 of arsenic, nickel and tin, bodies which cling to copper with more pertinacity than any of the other impurities.

Summary of the Production of Copper in the United Kingdom in the year 1859, the mean average Price of Fine Copper being £110 7s. 6d. per ton

—	Mines.	Copper Ore.	Value of Copper Ore.	Fine Copper.	Estimated Value of Fine Copper.
	No.	Tons.	£	Tons.	£
Cornwall & Devonshire sales	131	181,848	1,096,207	11,827	1,300,970
Swansea sales, deducting the Foreign Ores and Regulus, Slag, &c., as being chiefly of foreign production	10	18,041	170,068	1,767	194,570
Private contract purchases (estimated) . . .	29	36,900	240,560	2,176	239,160
Total	170	236,789	1,506,835	15,770	1,734,700

The Total Quantity of Copper produced from British, Foreign, and Colonial Ores in 1859, smelted in this country, was,—

	Tons.	cwts.	qrs.	lbs.
Fine copper produced from ores sold at Cornish ticketings	11,827	1	0	14
Ditto from ores sold at Swansea ticketings	5,497	10	0	17
Ditto from ores purchased by private contract, as by returns	12,589	13	3	19
Ditto ditto in addition (estimated)	2,800	0	0	0
Total	32,714	4	0	22

Estimated value in 1859 . . . . £3,588,540
Do. do. 1858 . . £3,417,149

Imports and exports of Copper for the year ending 31st December, 1859.

Description.	Countries.	Quantity.	Computed Real Value.
	Imports from—	Tons.	£
Copper Ore and Regulus	Spain	5,824	59,511
	Cuba	[illegible]	[illegible]
	Chili	[illegible]	[illegible]
	Australia	8,671	[illegible]
	Other countries	21,656	[illegible]
	Total	[illegible]	[illegible]

Copper unwrought and part wrought [illegible] Tons.

Exports of Copper.

Description.	Countries.	Quantity.		Declared Value.
	Exports from—	Tons.	cwts.	£
Copper unwrought, in bricks and bars.	Belgium	[illegible]	1	[illegible]
	France	4,321	9	[illegible]
	British East Indies . .	950	18	[illegible]
	Other countries	442	12	17,210
	Total	[illegible]	0	[illegible]

The number of persons employed at Swansea in 1858 in smelting copper was about 3,500, exclusive of colliers who raise the fuel. The shipping between Cornwall and Wales amounted to about 20,000 tons, and about 1,200 seamen were employed.

The number of calciners and furnaces at Swansea was about 550; 150,000 tons of coal per annum were consumed, about £3,000 per week was paid in wages. One foundry smelts 47,000 tons of ore yearly, producing 6,250 tons of copper.

COPPERAS, or *green vitriol* in its pure state, is protosulphate of iron FeO, SO_3. See IRON.

COPYING MACHINES, machines for multiplying copies of a writing, such as letters and circulars. The first machine of this kind was proposed by Dr. Franklin, who directs the letter to be written with gummed ink and sanded over with emery powder. It is then to be placed on a smooth plate of pewter and passed through a copper-plate printer's rolling press. The impression of the emery is left on the pewter, and printing ink being applied to the plate, an impression may be taken, which is a copy of the letter. It would seem, however, that the multiplication by means of the lithographic press would be as cheap and far more satisfactory in its results. In 1780 Mr. James Watt of Birmingham obtained a patent for copying recent manuscripts. A sheet of thin unsised paper is wetted and then placed between two woollen cloths to absorb the redundant moisture. Being laid on the manuscript, the two are passed together through a rolling or screw press, when the thin paper is found to have received a reverse impression of the letter, legible when read through the transparent substance of the paper. Mr. Watt proposed to wet the thin paper with a solution containing some of the constituents of ink, in order to make the writing more distinct. A better plan, however, is to write the document intended to be copied with a thick ink prepared for the purpose, or to add a little sugar to common writing ink. An improvement on Watt's machine by Mr. Ritchie of Edinburgh is shown in Fig 621, in which *b* is the bed of the press, *p* the platten, *hh* handles revolving on the screw *s*, which are used to draw down the platten on the paper, &c. placed beneath the screw works in a square piece of steel, which slides in a hole of similar figure on the head of the press, as shown by the dotted lines, and on the top is a small cam *c* worked by the lever *l*. The pressure is first given by means of the screw, and the cam being afterwards brought down vastly increases the force through a small space. Mr. Ralph Wedgwood obtained two patents for copying machines, the first in 1806, in which he proposes to employ, 1, a sheet of paper, over both sides of which printer's ink is spread: this is allowed to dry during six weeks between leaves of blotting paper; 2, a smooth pewter or copper plate; 3, on the metal plate is laid a leaf of letter paper; over it the blackened paper, and over this aleaf of thin paper previously oiled to increase its transparency; 4, on the paper thus disposed the writing is performed by means of an agate style, ground and polished to a smooth round point: the effect of which is that the letter paper receives an impression from the blackened paper, and this impression is in the right direction, and constitutes the letter which is to be used as the original. The upper oiled paper receives an impression which is inverted, but it may be read in the right direction by looking through the paper. This forms the duplicate or copy. The second patent (1808) was for a certain disposition of two leaves of paper by folding or rolling. The part of the sheet on which a line of the original is written, is brought close to the part of the other sheet on which the corresponding line of the duplicate is written. The line of the original and of the duplicate are formed at the same time by two pens fixed in the socket of one handle, which is held like a pen in the usual way. In Mr. Hawkins's polygraph, two or more pens are carried in a framework, and so connected by joints, that whatever motion is given by the hand to one pen the other pens describe similar figures; so that while a person is employed in writing a letter with one of these pens, the others make copies on separate sheets of

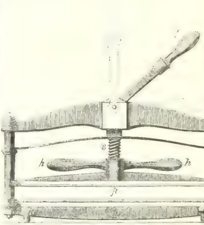

Fig. 621. RITCHIE'S COPYING-MACHINE.

paper. This machine, however, is somewhat complex, and is attended with some practical difficulties.

One of the simplest and probably, therefore, the best copying machines is the invention of Mr. Brunel. The bottom of the press *b*, Fig. 622, is made of gun metal; *p* is a pressing board of wood with a steel plate spring *s*, resting on ledges and supporting the pressing board by the screw *k*. A strong steel lever *l* moving on the plane *f*, presses near its centre on the head of the screw *k*; and *l'* is another lever moving on the joint *j*, to which the power of the hand is applied. The letter to be copied is damped by a metallic cylinder with several sheets of fine linen rolled round it, of the same size as the sheets of paper used. It is then put into a transferring book, and a blank leaf of paper is turned over upon it: a sheet of the damp linen is then laid upon the blank leaf, and above that a leaf of oiled paper: the book being shut and introduced between the bottom of the press and the pressing board, the hand is applied to the lever *l'*, which presses down the lever *l* with great force and communicates the pressure to the book by means of the knob *k* of the pressing board, thereby imprinting on the oil-paper a legible copy of the letter, inverted on the side next to it, but easily read on the other side of the transparent sheet.

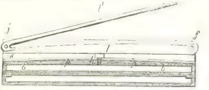

Fig. 622. BRUNEL'S COPYING MACHINE.

CORAL. The red coral of commerce, is the axis or inorganic framework of a species of polype, which is found in the Mediterranean and the Red Sea, growing arborescent at the bottom of the water, attached to stones, rocks, fragments of lava, &c. "In its natural state it is covered with a whitish rind, united to the axis by a reticulated membrane abounding with milky follicles: on the surface of the fleshy rind are thinly scattered tubercles with a cavity or cell, in which a milk-white and almost transparent polype is lodged, having the mouth surrounded by 8 conical tentacles. This fleshy rind becomes friable and chalky when dried." Red coral seldom exceeds the height of a foot, which it attains in shallow water in 8 or 10 years. It is of slower growth in deeper water. When full grown, it increases slowly in circumference, and at length the living rind dies, and the axis is attacked by various minute boring animals, which pierce it in all directions and destroy it. Coral grows at various depths, from 6 or 7 fathoms to 60 or 100. Along the French coast it seems to prefer the surface of rocks which incline to the south, and in the Straits of Messina it prefers an eastern aspect. The growth and quality of the coral seems to depend greatly on the influence of light and heat, and the most beautiful is obtained in shallow water. There are 15 varieties of coral distinguished in commerce, according to their degrees of hardness and brilliancy of colour, by such names as *froth of blood*, *flower of blood*, *first*, *second*, *third blood*, &c. The coral from the French coast and the Italian Seas is most esteemed, and the price is said to vary from 8 or 10 guineas an ounce, to less than 1*s.* per pound. On the African shores of the Mediterranean, the colour is less brilliant, and although the branches are thicker, the texture is less compact. Coral is composed of cartilaginous matter, with carbonate and phosphate of lime.

There are coral fisheries in many parts of the Mediterranean. The ground is divided into separate portions, one of which is dragged once every 10 years. The apparatus for dragging it is very rude: it consists of a large cross of wood, with a heavy weight in the centre, and nets properly secured to each limb; this is let down from a boat by means of a rope; the boat is then rowed over the coral beds, and the stems and branches are broken off by the machine, and become entangled in the nets. No doubt a good deal of coral is lost by this clumsy method.

Coral is not so much esteemed as formerly. In the middle ages it was used as a medicine, and the priests of ancient religions offered it to the gods.

CORBEL, a projecting piece of stone, wood, or iron, for supporting a weight of materials. The projecting of one stone beyond another, is called "corbelling out;" this is done both in masonry and brick.

CORDAGE, see ROPE.

CORK, the soft elastic bark or *cortex* (whence the word *cork*) of a kind of oak, (*Quercus suber*) inhabiting Spain and Portugal. "The bark of all trees consists of a parenchymatous or soft cellular substance, and of a harder ligneous tubular tissue; in most species, the latter is most abundant; in the cork, the former constitutes the mass of the bark, and hence its elasticity and the facility with which it is cut in all directions. When however it is first generated, the bark of the cork-tree is far less elastic than it becomes subsequently, which is owing to its consisting, in the first instance, of a large proportion of woody matter. When the latter is once formed, which takes place in the first year of its growth, it never increases, however long the bark may remain in the living state; but the parenchymatous substance will go on growing as long as the bark is alive, a provision of nature connected with the annual increase in diameter of wood, and the necessity of the bark giving way to the pressure from within. If the growth of the parenchyma is prolonged and rapid, a corky substance is the necessary consequence, as in certain kinds of elms, the common oak itself, and many other trees; but it does not occur in any European tree in such excess as in the cork. As soon as the bark dies, it of course ceases to grow, and then, not distending as it is pressed upon from within, it falls off in flakes which correspond to the layers that are formed annually. These flakes are the layers of cork, which the Spaniards collect under the name of the outer bark, while the inner living bark is or rather should be spared."[1] The cork-tree is most abundant in Catalonia and Valencia, whence the principal exports have been made. The cork is removed from the trees in July and August, for which purpose the bark is cleft longitudinally at certain intervals down to the crown of the root with an axe, the handle of which terminates in a wedge: a horizontal incision is then made round the tree from each extremity of the longitudinal cuts. The bark is then beaten to detach it from the liber, and the wedge-shaped handle being introduced, it is raised up and thus removed. The tree is about 15 years old when this operation is first performed; the first crop is not of much value, and the second, which is removed about 10 years after, is not very valuable. After this, the operation is repeated every 8 or 10 years, and the produce improves both as to quantity and quality at each operation. A tree thus barked will, it is said, live 150 years. After the pieces are detached, they are soaked in water, and when nearly dry, are placed over a fire of coals, which blackens their external surface, makes them smooth, and conceals the smaller blemishes; the larger holes and cracks are in some cases filled up with soot and dirt. The pieces are next loaded with weights to make them flat, and are afterwards dried and stacked, or packed up in bales for exportation. Unmanufactured cork is admitted into Great Britain free of duty; the import duty on corks ready made is 8*d.* per lb. Corks squared for rounding, pay 16*s.* per cwt., and fishermen's corks, 2*s.* per cwt. The quantity entered for home consumption amounts on an average to from 40,000 to 50,000 cwt. Its price varies with its quality, from 17*l.* to 60*l.* per ton.

The uses of cork are very numerous, and too well known to require description. Its elasticity renders it very valuable for stopping vessels of various kinds, in order to prevent the liquor from running out or the external air from passing in. The business of the cork-cutter may be thus briefly noticed:—The cork, after being pressed into square pieces, is received by the cork-cutters, and if not sufficiently flat for their purpose, they *lay* it again over a fire in their "burning yard," turning the convex part to the flame; the heat, by twisting the edges of the bark, counteracts the natural bend and flattens it out. During this operation, attention is paid to smoothing it, and covering its defects. It is next cut into slips, by means of a gauge, Fig. 623, set narrow or wide, according to the size of the intended *cork*, *bung*, or *tap*, as the varieties are called, the last being used for stopping the tap-holes of barrels. These slips are again cut into squares of the required length. This operation is performed by one man, from whom they are handed forward to several others. The corks are further divided according to their lengths into *short*, *long*, and *full long*.

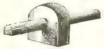

Fig. 623.

The cork-maker Fig. 625, is seated before the table or plank, on which is fasted a board Fig. 624, about 3 inches thick, 4 broad, and 12 long; immediately on a line with his left hand, is a piece of wood rising about 4 inches from the board, and fixed about the middle, on which the cork is laid after being cut as above. This wood not only supports the cork, and serves as a guide to the workman, but by its elevation above the board gives room for the knife to cut a part of the cork in a smooth and circular manner, without striking on the table below. The piece is then turned to the point where the last cut ended, and this is continued until the knife has gone completely round; the top and bottom are then pared level, and the cork is thrown into a box or basket with the others of the same length. As the bark is not of the same quality throughout each piece, the corks are sorted into *superfine*, *fine*, *common*, and *course*.

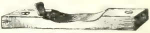

Fig. 624.

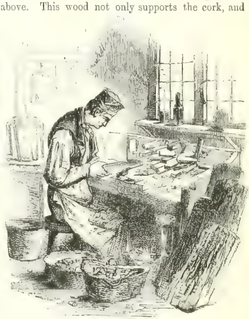

Fig. 625.

The cork-cutter's knife, Fig. 626, is a very thin and sharp blade, about 6 inches long, and tapering off from the handle to the point, as shown in the figure. This knife is sharpened upon the board where the guard is placed, by one whet or stroke on each side after every cut, and occasionally with a common whet stone.

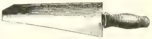

Fig. 626.

The chief art in cork-cutting, is to obtain a regular round and quick turn of the wrist in guiding the knife, so as to complete a tolerably accurate circle, and to make a smooth surface; on which account the knife must be very sharp to enable the men to turn it with ease.

The parings of cork are used for burning into Spanish black.

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[1] Penny Cyclopædia article *Cork*.

COTTON. The progress of the cotton manufacture in this country is one of the marvels of the age; and the vast amount of the capital and labour now employed in it leads us naturally to rank the cotton plant among the most valuable and important vegetable substances with which the earth is bountifully furnished. To appreciate in some degree its importance to this country, it is only necessary to bear in mind that the declared value of our exports in cotton goods amounted in 1860 to upwards of fifty-two millions of pounds sterling, while the quantity retained for home consumption was supposed to exceed twenty millions. This is a great contrast to the state of things in 1760, when the total value of all the cotton goods manufactured in Great Britain was only about two hundred thousand pounds. At that period, and for thirty years afterwards, North America did not supply us with a single bale of cotton; and there seemed very little prospect of our being in a condition to produce cotton goods that might compete with the fabrics of China and Hindustan, which had long been celebrated for their lightness and delicacy. That we should receive raw cotton from the East Indies, and return it to that country manufactured more dexterously than the celebrated native fabrics, would naturally have been looked upon by us and by the Hindoos as an impossibility. Yet, thanks to British skill and industry, and to the practical spirit of inquiry, which resulted in the invention of the steam-engine and of the spinning jenny, we are now in a condition not only to do this, but to import cotton largely from other quarters, and to surpass the whole world in the extent, beauty, and variety of our manufactures in that material. Of this all the nations of the earth are witnesses, for there is scarcely any part of the globe to which our commerce has not penetrated, and to which our printed cotton goods have not been conveyed. In the factories of Manchester, provision is made for the wants of the inhabitants of various climates, and for races uncivilized as well as civilized. The cotton dress of the African chief, or of the Chinese citizen, is there supplied, in common with the working dresses of our mechanics and their families, or the delicate muslin robes of royalty; and all this variety and extent of manufacturing skill, with its consequent vast amount of good to our labouring classes, is employed on a substance not indigenous to our own country, nor confined to our own colonies, but obtained from other nations with whom we hold friendly relations. This is a powerful argument in favour of free and unrestricted intercourse among the nations of the earth, by which an interchange of productions enables them effectually and thus extensively to help one another, to their mutual good.

Before the civil war broke out in America, we received about two-thirds of our supply of raw cotton from the Southern States, where the cultivation of the plant had been carried on to such an extent that it is reckoned that the labourers and helpers, together with owners, overseers, and their families, dependent on the crop, amounted to a million of persons. The cotton produced in the United States exceeded the production of the whole world in 1770: and this is to be attributed in some degree to the good quality of American cotton, the low price of land, and the improvements introduced into the various processes, but more than all, perhaps, to the energy and skill of the American planters, and the enterprising character of the nation. The cotton-plant (*Gossypium herbaceum*) which thus flourishes in that country, and in other warm climates, as India, China, &c., is a member of the order Malvaceæ, which contains our common mallow; nor is the plant much unlike the mallow, as our illustration will show. The same herbaceous character, the same structure of the blossom, which in some varieties is purplish, like the mallow, is in others of a pale yellow colour. But there is a very different appearance of the seed-vessel, inasmuch as from the surface of the seed-coat in the cotton-plant there springs up a thick growth of vegetable hairs, or filaments of considerable length, filling the seed-pod, and at length bursting it, and exhibiting a ball of snowy-white or yellowish down, consisting of three locks, one for each cell, enclosing and firmly adhering to the seeds, which resemble grapes in size and shape.

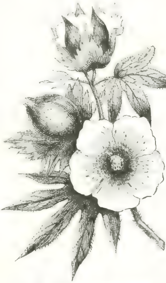

Fig. 6[illegible]7. HERBACEOUS COTTON.
(*Gossypium herbaceum.*)

There are many varieties of gossypium yielding cotton fit for the manufacture, and these have been divided into herbaceous, shrub, and tree cotton; the herbaceous being the most valuable. The above description refers to it; and the crop is described as a very beautiful one when the pods are progressively opening, the fine dark green of the leaf contrasting with the brilliant white of the cotton suspended from the pods, and floating to and fro at the bidding of the wind. This crop is annual; but shrub cotton, though annual in some cool climates, in others lasts two or three years, and in some cases from six to ten. The shrub is about the size of our currant-bush, and in the hottest countries it becomes perennial, and furnishes two crops in a year. Tree cotton is so called because it often attains a height of from twelve to twenty feet. But it must be carefully distinguished from the cotton-trees of the West Indies and of the American forests. These are prodigious trees, of quite another family, (*Bombax,*) with buttresses projecting from their huge trunks, and more remarkable for their noble aspect than for any useful purpose to which they can be applied. Many of them bear indeed clusters of a woolly substance enveloping the seeds and resembling true cotton; but there does not exist the same adhesion between the hairs, and the cotton of the Bombax cannot therefore be manufactured.

Fig. [illegible]. TREE COTTON.
(*Gossypium arboreum.*)

The true cotton-plants are cultivated on a light sandy soil, and in situations where other plants rarely flourish, namely, in the vicinity of the sea, and in what is generally considered very bad land. The saline breezes evidently favour its growth, and the American *sea-island* cotton, which is cultivated on the low sandy islands from Charlestown to Savannah, has long been celebrated for its long fibre, and its strong and silky texture. The cultivators of Georgia and the neighbouring states grow three varieties of herbaceous cotton: the first, from its yellow colour called *nankin* cotton, the second *green-seed* cotton, the third *sea-island* cotton. The first two grow in the midland and upland districts: hence a fine white variety is known as *upland cotton,* or, from a method of cleaning it, *bowed Georgia cotton.* There are also other technical names in use in the trade.

The cultivation of the crop is carried on with great care and attention in the United States. The seed is sown by hand in March, April, and May, in rows five feet apart, each row having its seeds planted in holes eighteen inches asunder, and with several seeds in each hole. The land is kept well weeded, and when the plants come up, the weakest are drawn out, leaving two or three strong plants in each hole. A few months later, they are again thinned, and *topped* to the extent of an inch or two. This checks the upward growth, and promotes the development of side branches. When the cotton is ripe, a number of women and young people go into the field with baskets or bags suspended from their shoulders, to pull the cotton. That which is sufficiently ripe can be gathered with the seeds, without the outer husk, which is the best way; for if the whole pod is gathered, the husk breaks into small pieces, and once mixed with the cotton, cannot be easily separated from it. This crop is liable to damage from wet seasons, which cause diseases called *blast* and *gangrene;* and also from insect enemies, the chief of which are the *cotton bug,* and the *chenille,* or *cotton caterpillar.*

When a good store of cotton has been gathered in and dried, the next task is to separate the seeds from the wool. If this is done by hand, a man can scarcely clean more than a pound of cotton in a day. A rude hand-mill, or roller-gin is therefore substituted in some parts of India and China, by which from forty to sixty-five pounds can be cleaned in a day. After this, the cotton is further cleared from dirt and knots by *bowing.* A large bow being placed in a heap of cotton, the string is made to vibrate powerfully, and this disperses and cleanses the heap. These means employed from remote times in Asia, were also formerly used in America; hence the term *bowed Georgia cotton.* The sea-island cotton is still separated from its seeds by rollers constructed on a large scale, and worked by horses, steam, or water. These rollers are of wood, and revolve rapidly in contact with each other; as they do so, a sort of comb with iron teeth acts on the cotton as it passes between them, and detaches the seeds, which fly off like sparks in all directions. Particles of seeds which escape and pass through with the cotton, are removed by hand. This is called *moting.* The cotton is then whisked about in a light wheel, and when well winnowed, it is conveyed to the packing house, and forced into bags by means of screws, until each bag contains from 300 lbs. to 350 lbs. Short-stapled cotton cannot be properly cleaned by this process. The seeds are so firmly attached to the wool, that a more powerful machine called the *saw-gin,* invented by Eli Whitney of Massachusetts, is put in requisition, and will clean 3 cwt. in a day. The cotton is put into a long and narrow hopper, one side of which is formed by a grating of strong parallel wires, ⅛th of an inch apart. Close to the hopper is a roller set with circular saws, an inch and a half apart. These, as they revolve, pass within the grating of the hopper to a certain depth, and seize by their teeth on the locks of cotton, dragging them through the wires, which are not wide enough apart to allow the seeds to pass also. The cotton is afterwards swept from the saws by a revolving cylindrical brush. Thus the separation is effected in a cheap and easy manner, but not without some injury to the fibre of the cotton. All the North American cotton, except the sea-island, is subjected to this process, and since the saw-gin came into operation in 1793, there is nothing in the history of industry to compare with the increase of the American trade in cotton, unless it be our own progress in the manufacture of the same article. In 1792, the total exports of cotton from the United States to various parts of the world, amounted to 138,328 lbs. only. In 1860, the cotton sent from Great Britain to the United States *alone* amounted to 1,115,890,608 lbs. At the present time (1862), when the States, no longer United, are unhappily engaged in civil war, and the southern ports blockaded by the Northerners, our supply of raw material from that source is cut off, to the no small inconvenience of our vast cotton-manufacturing population, and the anxiety of the nation. Our means of supply from other sources will be stated in the APPENDIX, but we may here state that British India is in a good way of supplying a large portion of our deficiency.

While wool and linen are abundantly alluded to by ancient writers, both sacred and profane, we find few among the latter, and not one among the former referring to cotton. Its growth and manufacture appear to have been quite unknown to the Egyptians, for no specimen of cotton has ever been found among their mummy-cloths, or painted on their tombs, while flax is accurately represented thereon. But while the linen manufacture alone occupied the ancient Egyptians, there is every reason to believe that at the same early period, cotton was manufactured in India. Herodotus, 445 years before Christ, said that the Indians were accustomed to make their clothes of a sort of *wool*, which grew on plants, and was finer and of better quality than that of sheep. Strabo on the authority of Nearchus, likewise speaks of the Indians as being celebrated for flowered cottons or chintzes, and for their various and beautiful dyes. The calicoes, muslins, and other cottons, both plain and ornamented, were among the exports from India in the time of Arrian, who lived in the first or second century. The muslins of Bengal had then attained their celebrity, and were called by the Greeks *Gangitiki*, to denote that they were made on the borders of the Ganges. The Indian fabrics gradually came into use in Arabia and the neighbouring countries, and were diffused by the commercial activity of the followers of Mohammed. *Mosul* in Mesopotamia, is said to have been the origin of the word muslin, while *Calicut* gave its name to calico, and *Nankin* to the cotton fabric known as nankeen. The cotton-plant grows plentifully on the borders of some African rivers, and a few years ago was introduced into Egypt, where the soil and climate appear to be admirably fitted for its growth. As the seed planted there was from the Georgian Sea-island plants, the cotton brought to England from Egypt is known as *Sea-island Egyptian cotton*.

On the discovery of America, the cotton manufacture was found to be in an advanced state in that country. Cortez sent presents to Charles V. of cotton mantles of various colours, waistcoats, handkerchiefs, counterpanes, tapestries, and carpets of cotton. The rest of Europe received from Spain the cotton manufacture. The plant was grown at Valencia, and an extensive manufacture of sail-cloth and fustian was set up at Barcelona. Cotton yarn began also to be imported into Europe from Syria and Asia Minor. The early history of our own attempts at this manufacture, refers to a heavy and coarse fabric called *muslin*, but of too rude a kind to deserve much notice. No fine goods appear to have been made in Europe until the invention of the spinning machinery of England. The time of the actual commencement of the cotton manufacture in our country is difficult to settle: the more so, that there is a confusion of terms, by which the woollen and linen fabrics of Lancashire were called *cottons.* Camden speaking of Manchester in 1590, alludes to "the glory of its woollen cloths, which they call *Manchester cottons*." The earliest actual record of the cotton manufacture is by Roberts, in 1611, who says of the people of Manchester: "They buy *cotton-wool* in London, that comes first from Cyprus and Smyrna, and at home worke the same and perfect it into *fustians, vermillions, dimities*, and other stuffes, and then return it to London, where the same is sold, and not seldom sent into forrain parts, who have means, at far easier termes, to provide themselves of the said first materials."

The preparation of yarn for the weaver was formerly a domestic employment, common to all ranks of society in England, as the term "spinster" universally applied to unmarried females sufficiently shows. The distaff and spindle were the earliest instruments employed. The former was a stick or reed 3 feet long, with a fork near the top, on which the carded cotton was wound. This distaff was held under the left arm, and the fibres of cotton drawn from it, and twisted spirally by the action of the thumb and forefinger of the right hand. The spindle was a reed scarcely a foot long, in fact, a mere winder on which to wind up the thread; at the top was a slit to attach the thread, and at the other end was a whorl or wheel to steady it. The thread being attached to the spindle was drawn from the distaff until a sufficient length had been gained for the attached spindle to touch the ground, a fresh turn being frequently given to the spindle to increase the twist of the thread. As soon as the spindle reached the ground, "a length" was said to be spun, and the spinster, winding it up on the spindle, and securing it firmly in the slit, proceeded to spin another "length." The Hindoos make their spindles from the shrub *Euonymus*, which has hence obtained the popular name of the spindle-tree. These simple implements were superseded in England in or soon after the reign of Henry VIII. by the spinning wheel, which had been in use for ages in Hindustan; and in improved forms, and according to the places whence we received it, was called in this country the *Jersey wheel*, *Saxon wheel*, &c. This was a large wheel, over which passed a band or cord in connexion with the spindle, and giving motion to it. One slow revolution of the large wheel of course produced rapid and numerous revolutions of the spindle on its axis. The cotton was first *carded* or brushed with coarse wire brushes, called *hand cards*, until the fibres were all arranged in one direction, and soft fleecy rolls had been produced, each a foot long: one of these was taken and attached to the spindle, the spinster then turned the wheel with one hand, and drew out the carding with the other. The motion thus given to the carding twisted it spirally, and increased its length. It was then wound upon the spindle, and another carding was attached to it, twisted, and drawn out like the other, so as to form a continuous thread, or *roving*. This was called coarse spinning, and a repetition of the process was necessary to reduce this roving to a tolerably fine thread. But at the best it was a very unequal thread, its evenness depending on the greater or less delicacy of touch of the spinster. It was necessary to use the firmer and more equal thread of flax for the warp, the woof only being of cotton. The spinning wheel gave profitable domestic employment to women and children, but its use was, perhaps, the origin of infant labour, and caused severe tasks to be inflicted on the young. All these efforts could not meet the rising demand for cotton yarn, and a weaver had sometimes to walk three or four miles of a morning, and call on five or six spinsters before he could collect enough weft to serve him for the remainder of the day; and when hard driven for a supply, he would quicken the exertions of the spinners by the promise of a new ribbon, or a gown. This great difficulty felt by weavers of getting a due supply of yarn for their looms, at last stimulated the invention of one of their number, an industrious but illiterate man, James Hargreaves by name. He had often tried to spin with two or three spindles at once, holding the several threads between the fingers of his left hand, but the horizontal position of the spindles frustrated his attempt. It is said that one day his children upset the spinning wheel while he was at work, and as he retained the thread in his hand the wheel continued to revolve horizontally and the spindle vertically. This excited his close attention, and he continued to turn the wheel as it lay on the floor, and to watch the motion of the spindle with an interest which no one about him could understand. The happy thought had now occurred to him that if a number of spindles were placed upright, and side by side, many threads could be spun at once. He, accordingly, contrived a frame, where eight spindles were placed in a row, and eight rovings attached to them, the other ends being received by a fluted wooden clasp, which opened and shut like a parallel ruler, and when pressed together held the threads fast. This clasp was drawn by the left hand along the frame to a considerable distance from the spindles, while the spinner with his right hand turned a fly wheel, thus keeping all the spindles in rapid motion, and giving the cotton the requisite twist. Eight lengths being thus spun they were wound on the spindles, and the clasp being returned to its first position, was again opened by a simple contrivance called the "knocker off," and fresh lengths of roving attached and spun out as before. The number of spindles afterwards attached to this frame was increased from eight to eighty. Thus arose, about the year 1764, the *Spinning Jenny*, Fig. 629, named, as some say, from its doing the work of a female, but as a grandson of Hargreaves has informed the Editor, from the word *gin*, a contraction of *engine*, the new machine being called a *ginny*, and the process *ginning*. These terms are said to have begun with Hargreaves' wife, who commended her daughter Mary's spinning with the new frame by saying,—"Thou *gins* away famously." Coming from so good a source, we may perhaps conclude that this is the true origin of the word, though it is frequently said to have arisen from the Christian name of the inventor's daughter, and it is very possible he may have had a Jane among his twelve children. Hargreaves kept his discovery quiet for some time, but the quantity of cotton spun by his family excited suspicion, and at last other spinners broke in, and destroyed his machine. He then removed to Nottingham, and erected a small spinning mill on the jenny plan. He also took out a patent, and on its infringement he brought an action, and a deputation waited on him with an offer of 3000*l.* for permission to use his machine. In an evil hour he declined this, and subsequently, when it was found that he had sold several of his machines before he took out his patent, he lost all claim to redress and compensation, and was very little benefited by what was an invention of great national importance. He died in 1778, not in poverty and distress, as it is often stated, for he left his family 500*l.*, but still without the reward which his merits deserved. The late Sir Robert Peel bestowed on his youngest, and only surviving daughter, a few years back, the sum of 250*l.* from the Royal Bounty Fund.

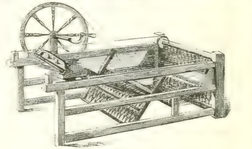

Fig. 629.—THE SPINNING JENNY.

The invention of Hargreaves, important as it was, did not keep pace with the great and increasing demand for yarn. But there was another genius at work, soon to produce more powerful machinery, which would, to a certain extent, throw into the shade all previous inventions. This was Richard Arkwright, of Preston, in Lancashire; a poor youth, apprenticed to a barber, afterwards a barber on his own account at Bolton, and a dyer of hair for the wig-makers, in which latter art he is said to have contrived and employed a chemical process of some value. Besides this he was a mechanical genius, and busied himself, as many self-educated mechanics are accustomed to do, in the pursuit of that will-o'-the-wisp, *perpetual motion.* In this way he became acquainted with Kay, a clockmaker at Warrington, who is said to have given him the first idea of a scheme for spinning by rollers. As early as 1738, Wyatt, of Birmingham, and his partner Paul, a foreigner, had taken out a patent for such a machine, being the invention of Wyatt; but this, after two years' trial, was given up. A similar machine is said to have been made by one Highs, a friend of Kay, the clockmaker; but this does not rest on very sure evidence. At any rate, the idea must have been imperfect, if conveyed in this way at all, for Arkwright wrought with long patience and constancy, and abandoned every other employment to perfect and complete his idea of a spinning machine. His great poverty made it difficult for him to get the requisite assistance in the heavier parts of the work; he, therefore, made application at his native place, and at length, money being kindly supplied by Mr. Smalley, the head-master of the Grammar School at Preston, Arkwright's machine was brought to completion, and first fitted up in the parlour of the house belonging to the school.

Arkwright now removed to Nottingham, where Hargreaves had previously taken refuge, and there sought a partnership which might enable him to bring forward and patent his machine. This he found in Messrs. Need and Strutt, the latter of whom was the improver and patentee of the stocking-frame. A patent was taken out in 1769, and the partners erected a mill near Nottingham, where the machinery was worked by a water-wheel, and came in consequence to be called the *water-frame,* and the yarn, the *water-twist.* The first great improvement accomplished by the new machine, was the production of a firm hard thread fit for warps, so that linen warps were henceforth abandoned. Calico, in imitation of the Indian fabric, was also made, but this was soon checked by the Excise, who actually refused to let it pass at the usual duty of three-pence per yard, and insisted upon sixpence, as for Indian goods. The partners were put to much expense before they gained permission by act of Parliament to manufacture calico, which was to be distinguished from the foreign by three blue stripes woven in the warp of both selvages, and by the word "British Manufactory" stamped upon it. Arkwright's active mind was continually engaged in improving his own machines, and also those used in the preparatory processes of the cotton manufacture. He was the first person who ever erected a cotton-mill, and formed a distinct idea of all the processes to be carried on therein. He knew all the changes the fibres must undergo, from the tangled cotton-wool to the finished thread, and when an imperfection occurred in his yarn, he could in a moment state which of the processes had in that case been defective. Thus the merit of perfecting the carding machine belongs to Arkwright, for he combined the various improvements on the old hand-cards, which had been made by other men, with clever devices of his own. In 1775, he had made such extensive alterations in a series of machines, including carding, drawing, and roving machines, that he considered himself justified in claiming them as his own by a second patent. His fame was now great, and in 1782 it was calculated that 5,000 persons were employed in his factories, while numbers of manufacturers flocked to buy his patent machines. The origin of the factory system is referred to this period, although a few silk-mills had existed since 1719. The cottages of the spinners could not accommodate the new forms of machinery, which also required substantial buildings to bear their weight, and water-wheels to work them to advantage.

Arkwright was not allowed to enjoy his second patent very long; it was disputed by the Lancashire spinners, and eventually thrown open to the public. Arkwright opposed the verdict, and there were several trials, but he lost his cause, and this was undoubtedly a national advantage, for the manufacture soon acquired an extent and importance which could not have occurred had it continued to be a monopoly. Arkwright shared with others in the great prosperity which followed. He was looked to in adjusting prices, he was advanced in importance by being appointed High Sheriff of Derbyshire, and was at length knighted, on the occasion of his presenting an address to king George III. So much for the barber's apprentice, who made his own fortune by wonderful ardour, energy, and perseverance. He was accustomed to labour from five in the morning till nine at night, and to make up for the defects of his education, he began at more than fifty years of age to steal two hours from sleep each day that he might learn English grammar, writing, and orthography.

Hargreaves and Arkwright had thus produced spinning-machines of great value, and by their means had opened a new era in the cotton manufacture. But the yarn they obtained was not of fine quality, and was therefore only adapted for the stronger and coarser descriptions of goods. The happy thought now occurred to a young weaver, Samuel Crompton by name, to combine the roller spinning of Arkwright with the jenny spinning of Hargreaves, and in doing so, to get rid of some objections which applied to them separately. By a perfectly original contrivance he effected this union, and the new machine was called the *mule,* or the *mule-jenny.* In this machine, the spindles instead of being stationary as in the former cases, were placed on a movable carriage, or "mule," which was wheeled out to the distance of about five feet, in order to stretch and twist the thread, and wheeled in again to wind it on the spindles. This invention was perfected in 1779. Crompton's object had merely been to supply his own loom with good yarn; but when he found he could not do this in peace, owing to the curiosity of many persons, who even climbed up to his windows to watch him at work, he laid his invention before a number of gentlemen and others, who paid a guinea each to examine it. He thus raised about fifty pounds, with which he constructed another machine, larger and more perfect than the first. The mule jenny not being protected by patent, soon came into most extensive use, without any great benefit to the inventor. Yarn fine enough for muslins was spun by it, hence it was called the *muslin-wheel.* It was also known as the "Hall-in-the-wood wheel," from an old mansion in a retired and beautiful spot near Bolton, where Crompton lived. This mansion has been described as "one of the most perfect specimens of the domestic architecture of our Saxon ancestors, and of their descendants the Franklins, or old country gentlemen of England, who never bowed their head to the Norman yoke, and who refused to adopt the fashions imported from the continent." Beyond is the hill, on which stands the busy town of Bolton, while the intervening valley is studded with factories and bleach works. In the year 1812, some gentlemen of Manchester memorialized the government on the subject of Crompton's claims, and the result was a grant of 5,000*l.* With this sum Crompton established his sons in the bleaching business, but from some unfortunate circumstances they failed, and the father was again reduced to poverty. His friend and biographer, Mr. Kennedy, then exerted himself to raise a subscription, and with this a small annuity was purchased, but Crompton did not live to enjoy it more than two years. He died in 1827. His machine as first invented was adapted to carry 20 or 30 spindles only; now double mules are made carrying 1,100 or 2,200 the pair, one spinner being competent to manage them. Self-acting mules are also now constructed, the only manual labour being to join the broken threads and keep the machine in order.

Fig. 63. HALL-IN-THE-WOOD, NEAR BOLTON.

At one time, Crompton's machine seemed likely to supersede all others, but when the *power-loom* came into use, twist for warps was required to possess that strength and wiry smoothness which the water-frame produced; that machine was therefore remodelled, and came into use under the name of the *throstle,* on account of the singing sound produced by the motion of the arms of the spindle.

The causes which have determined the principal locality of the cotton trade in Manchester and its neighbourhood, are certain natural and physical advantages which belong especially to the southern part of Lancashire, namely, the possession of water-power, fuel, and iron. These advantages also belong, in a less degree, to the south-western part of Yorkshire, to Cheshire, Derbyshire, and Nottinghamshire, and also to Renfrewshire and Lanarkshire in Scotland, and consequently these districts share in the cotton trade.

Where water-power, fuel, and iron are abundant, machinery may be manufactured and set in motion at the smallest cost; and the processes of making and finishing cloth, depending, as they chiefly do, on the agency of water and heat, may also be conducted with advantage.

"The tract lying between the Ribble and the Mersey, is surrounded on the east and north by high ranges of hills, and has also hills of some magnitude in the hundred of Blackburn and Salford; owing to which cause the district is intersected by a great number of streams, which descend rapidly from their sources towards the level tract in the west. In the early part of their course, these streams and streamlets furnish water-power adequate to turn many hundred mills; they afford the element of water, indispensable for scouring, bleaching, printing, dyeing, and other processes of manufacture; and when collected in their larger channels, or employed to feed canals, they supply a superior inland navigation, so important for the transit of raw materials and merchandise."[1] No less important is the great abundance of coal found in the very same district. Beds of this invaluable mineral lie beneath almost the whole surface of Blackburn and Salford hundreds, and run into West Derby, to within a few miles of Liverpool, and being near the surface, they yield their treasures easily. The southern part of Lancashire contains very little iron, but being at no great distance from the iron districts of Staffordshire, Warwickshire, Yorkshire, Furness, and Wales, with all of which it has easy communication, it is as abundantly and almost as cheaply supplied as if the iron was got within its own boundaries. Another great advantage of Lancashire is its well situated port, Liverpool, "through the medium of which it receives from Ireland a large proportion of the food

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(1) History of the Cotton Manufacture in Great Britain, by Edward Baines, Esq. Jun. London, 1835.

that supports its population, and whose commerce brings from distant shores the raw materials of its manufactures, and again distributes them, converted into useful and elegant clothing, amongst all the nations of the earth." Through the same means, a plentiful supply of timber is obtained for building. To these natural advantages must be added the acquired advantages of canal and railroad communication with other parts of Britain.

The American cotton grower frequently consigns his cotton to this country for sale on his own account; but about three-fourths of the whole quantity sent is consigned by mercantile houses. The cotton is sold in Liverpool by brokers employed by the importers, and they charge 10s. per cent. for their trouble in valuing and selling it. The purchasers are the Manchester cotton dealers and spinners all over the country, and they also employ brokers at the same rate of commission to make their purchases. The cotton is principally bought and sold by sample, and the purchasers very rarely examine the bulk. Fig. 631 is a bag or bale of cotton.

Fig. 631.

SORTING.—When the cotton arrives at the mill, the bags are unpacked and sorted. The *sorting* requires judgment, because the qualities of the cotton differ somewhat in different bags, and the yarn to be spun from it must be of uniform quality. In order to equalize the different qualities, the contents of all the bags of one lot are mixed together in the following ingenious manner. A space is cleared and marked out on the floor, and the cotton of one bag is scattered all over this space, or on a clean mat spread thereon, so as to cover it exactly; the contents of the second bag are in like manner spread over the first; the third upon the second, and so on, until all the bags are thus formed into a kind of cotton stack, called a *bing* or *bunker*. While this is in process of formation, it is trodden down by men and boys, just as hay is in stacking. Now it will be obvious that if a supply of cotton for the purposes of the mill be taken from the side of this bing, tearing it down with a rake from the top to the bottom, a portion of every bag must be taken in every quantity thus pulled down, and in this way uniformity in quality and colour may be ensured. It is usual in forming a bing with different qualities of cotton to use those which have a similar length of staple; and for making the lower descriptions of yarn, some of the waste cotton of the mill is also used. For yarns of higher numbers, and for warps, a finer quality of cotton is selected. Fig. 632 shows another method of forming a bing. "Much skill may be shown in the suitable intermixture of different kinds of cotton, in order to improve a weak-stapled quality, and make it work into good yarn. Soft, short, riband-like filaments are best adapted for spinning into wefts; firm, long, and cylindrical ones are best adapted for making the wiry warps and hard thread yarns. Cottons which differ much in the length of their staple and form of their fibres do not draw, rove, or spin well together. Coarse wefts are made from Surats, Bengals, and the inferior Uplands, with waste tops from the drawing-machine; but the better wefts for muslins require the finer staples of Bahia, Demerara, New Orleans, and the inferior sea-islands. Warps are spun from New Orleans, Egyptian, Maranham, Pernambuco, and sea-island, &c."[1]

Fig. 632. SORTING AND BUILDING.

WILLOWING.—The cotton in the bing is matted together by the pressure to which it was subjected in packing, and it is also contaminated with sand, dirt, and other impurities. The fibres are opened, and the cotton is cleaned by a machine called a *willow*. This consists of a box or case, containing a conical wooden beam, studded over with iron spikes, and passing between other spikes fixed in the case or cover of the machine. The beam is made to revolve rapidly, and the cotton as it is torn down from the bing, being put in at one end of the machine, is caught by the spikes, and tossed and shaken about, and gradually driven forward to the other end. The sand and other heavy impurities fall out through an open grating at the bottom of the machine; the dust and lighter matters pass off through a series of wire openings into a shoot in which a draught is created by means of a revolving fan, while the cleaned cotton passes down a shoot into the floor below. In some of the early forms of this machine, a cylindrical cage was made of *willows*: hence the origin of the name.

BATTING.—Cottons of fine quality are not passed through the willow: they are beaten or *batted* with twigs of hazel or holly, 3 or 4 feet long, upon a frame,

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(1) "The Cotton Manufacture of Great Britain." By Andrew Ure, M.D., &c., 2 vols. 12mo. London, 1836. A bale of cotton varies in weight according to the market from which supplied. A bale from the United States has gradually increased from about 250 lbs. to an average of 440 lbs. Egyptian cotton weighs about [illegible] lbs. per bale, East Indian 276, West Indian 201, and Brazilian [illegible]. We must, however, repeat that the trade in raw cotton is at the time of the revision of this article in a transition state, in consequence of the civil war in America. See AMERICA.

the upper surface of which is made of cords, so as to form a kind of elastic grating. A woman with a rod in each hand, (Fig. 633,) beats the cotton violently, by which means the tangled locks become completely opened, and are made quite clean, without injuring the staple: the loose impurities fall out through the openings between the cords; but the fragments of seed pods, which adhere somewhat firmly to the cotton, are picked out by hand.

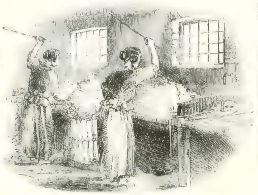

Fig. 633. BATTING COTTON.

SCUTCHING, BLOWING, and LAPPING.—For the coarser varieties of cotton, the batting is performed in what is called a *scutching* or *blowing-machine*. A few years ago, when the Editor visited Mr. Orrell's mill at Stockport, the following was the arrangement: "The cotton, as it was shot down from the willow, was received upon an endless band called a *creeper*, ingeniously covered with laths of wood moving upon rollers: it supplied cotton to the various blowing-machines, placed at equal distances apart across a long room. Each machine was attended by two lads, one of whom weighed a portion of the cotton, while the other spread it upon an endless band employed to feed the machine. This band was also formed of laths, placed crosswise, and fastened together, in preference to cloth, which is apt to sink along the middle, and thus feed the machine irregularly. Two or three of the laths were painted black, for the purpose of dividing the surface of the feeder into two or three equal parts. The feeder being constantly urged, with a slow motion, towards the mouth of the machine, it was the duty of the attendant, as soon as a black lath appeared, to begin to spread the weighed quantity of cotton, and to make it cover the whole surface until another black lath appeared: he was then ready to spread another weight of cotton. Thus, while one part of the feeder is constantly supplying the insatiable appetite of the machine, another part returns for a fresh supply. As soon as the cotton enters the jaws of the machine, it is seized by two rollers, and immediately exposed to the blows of a *batting-arm*, or beater, which is turned round with great velocity within a kind of drum, of which the arms of the beater form the diameter. The solid impurities fall through a grating, but the dust and lighter matters are sucked up through a shoot, in which the air is rarefied by a revolving fan. The wind produced by the batting-arm drives the light cotton filaments onward, where they are assaulted by another batting-arm: they are again urged forward, and blown with tolerable regularity over the surface of a wire-gauze drum, which is constantly revolving. Beneath this drum, and in close contact with it, is an endless band, moving on rollers, which receives the cotton, and conveys it out of the machine. The pressure of the drum upon the band condenses the cotton into a filmy sheet; that is, the fibres cling together sufficiently to allow the cotton to be wound upon an iron rod as it leaves the machine, and in this state it is called a *lap*. The advantage of this is, that a uniform thickness can be presented to the carding-engine, which is a necessary condition."[1]

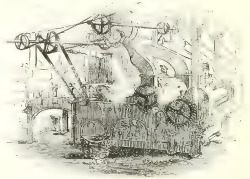

Fig. 634. BATTING AND LAPPING MACHINE.

The means by which these arrangements are carried out will be understood by referring to the longitudinal section of a batting and lapping machine, Fig. 635. The feed-apron is about 8 feet long: part of it is shown at A, where one end passes over a roller *a*, and its further end over a similar roller beyond the limits of the figure. The willowed cotton is spread by hand in weighed quantities, about 2 inches thick, upon the apron-cloth A, and is carried forward by it, at the rate of about 3 feet per minute, to the feed-rollers, *b*, which are pressed together by a weight acting on a lever *c* upon the brasses of the top rollers. A wooden roller *d* keeps the cotton close to the apron, and guides it between the feed-rollers, which are small coarsely fluted iron cylinders. B is the first beater, consisting of two flat bars *e e*, fixed at right angles upon a revolving shaft, so as to strike upon the cotton filaments as they issue from between the feed-rollers. This, the scutching-shaft, makes 2,000 turns per minute. C is the *harp*, a grating or grid, in the form of a quadrant of a cylinder, composed of long flat bars, against the edges of which the cotton is scutched by the beaters, and thereby thoroughly opened, after which it is wafted upon the endless apron D. This apron is formed of thin spars of wood, about ¾ inch broad, and ½ inch apart, fixed

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(1) "The Useful Arts and Manufactures of Great Britain." By Charles Tomlinson. Published under the direction of the Committee of General Literature and Education, appointed by the Society for Promoting Christian Knowledge. 2 vols.

at their ends to two endless leather straps, which turn round the rollers *f* and *g*, which are driven by the outside wheelwork, seen in Fig. 634. Near the end of the apron is a revolving cage cylinder E, enclosed under the cover *h h*, in the top of which is a pipe *i* in communication with a revolving fan. This cylinder allows the dust to pass through it, and also serves to spread upon the apron the loose cotton filaments into a level fleece, which passes off under the wooden roller *h*, and is thence drawn in by the second pair of feed-rollers, *l*, in order to be exposed to a second scutching by the beater-bars at F, the axis of which revolves 2,200 times per minute. This beater delivers the filaments upon a second apron G, where it is exposed to the sucking action of a second sieve cylinder, communicating by the orifice *m* with the fan ventilator. There the cotton is again formed into a fleecy mass, and is carried through between the two pairs of iron rollers *o o* and *p p*, the upper ones being weighted. These rollers deliver the compressed fleece to the wooden lap cylinder I, whose axis is loaded by hanging weights as at L, so as to bear down between the two rollers K K, which, revolving both in one direction, carry round with them, by friction alone, the lap cylinder. As this cylinder increases in diameter, the links *q* progressively rise up, with their weights L, so that the pressure continues always uniform. When the coil of lap has attained the proper size, the twin rollers *o o*, with the aprons, cages, and feed-rollers, throw themselves out of gear, whilst the twin rollers *p p* and the lap cylinders continue to revolve, whereby the fleece is torn or cut across in the middle line between the two pairs of twin rollers. The attendant now lifts the lever *r*, which raises the links *q*, and suspends the weights L by the hook *s*. In this way he relieves the axis of the lap cylinder, removes it, and puts an empty one in its place. He next throws the machinery once more into gear, disengages the connecting-rod *t* from the hook *s*, and restores the action of the weight, while he guides the beginning of the fleece round the empty roller.

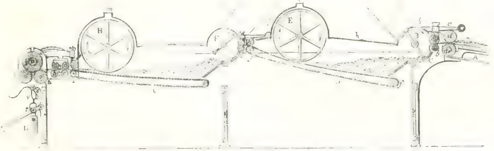

Fig. [illegible]. SECTION OF BATTING AND LAPPING MACHINE.

In fine yarns, the laps are prepared by hand. In Mr. Houldsworth's mill, at Manchester, the Editor watched the process, and it was performed in the following manner:—A lad was furnished with two qualities of cotton in separate baskets, from one of which he took a certain quantity, and put it, together with a small weight, into a scale-pan; when the scale-pan, thus loaded, counterbalanced the weight at the opposite end of the beam, the small weight was taken out of the scale-pan, and its equivalent was made up from the second basket. In this way, cotton of various degrees of fineness could be mixed in any proportion. If, for example, a yarn is to be produced from two qualities of cotton, in the proportion of 3 of one to 2 of the other, the large or counterpoise scale-weight is $1\frac{1}{4}$ or $\frac{5}{4}$. The lap-maker first puts into the scale-pan a weight equal to $\frac{2}{4}$ths, and cotton equal to $\frac{3}{4}$ths; then taking out the $\frac{2}{4}$ths weight, its place is supplied by another sample of cotton. But to return to our description:—The cotton thus weighed out was taken to a canvass strip, one half of which was extended along a kind of frame, the other half resting on the floor. The lad distributed the cotton over this cloth, batting and flattening it out with a kind of fan, formed by tying four or five thin rods together. The canvass thus covered with cotton was then rolled upon an iron spindle, and the act of rolling drew upon the frame the second half of the canvass from the floor: this was also covered with cotton and then rolled up. In spinning fine yarns, all the preparatory stages require great care, and the formation of these laps for the carding engine is a work of nicety. Should the cotton be spread irregularly, the uniform thickness of the yarn may be interrupted. Some manufacturers even make a compensation for hygrometric changes in the weight of the lap: the cotton varies slightly in weight according as the weather is wet or dry; and as a metal counterpoise is uniform, a variable counterpoise is made by packing a hollow perforated copper tube or ball with cotton: as this

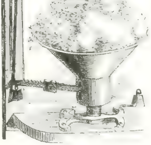

Fig. 636.

weight is about as much affected by atmospheric changes as the cotton which is to be weighed, an equality is thus preserved in forming the laps.

Of late years a very convenient balance, Fig. 636, of American invention, has been used. It acts on the principle of the steel-yard. It is also shown in Fig. 637.

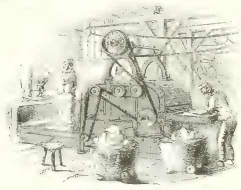

Fig. 637. LAP MACHINE.

CARDING.—The cotton, as left by the preceding operations, is in a tangled state, and not entirely free from impurity; but by the next operation—that of *carding*—the fibres are separated, made somewhat parallel, and freed from the remaining impurities. A cotton card is a sort of wire brush, made of bands or fillets of leather, or of alternate layers of cotton, linen, and India-rubber, pierced with numerous holes, in which are fixed bent pieces of hard-drawn iron wire, called *dents* or *teeth*. Each piece of wire is first bent at right angles, as at *a* and *b*, Fig. 638; then each limb must receive a second bend, as at *c* and *d*, Fig. 640, at a determinate obtuse angle, which must be invariable for the same set of cards. The teeth thus formed of equal size and shape must stand at equal distances, and be equally inclined to the curved surface of the drum round which the cards are to be lapped. The leather must also be of equal thickness throughout.

These conditions, which are necessary to good carding, cannot be secured in hand-made cards. Accordingly, many attempts have been made to construct a card-making machine, the most successful of which is that by Mr. Dyer. The leather is first prepared for it by a planing machine, which cuts it into fillets of the proper length and breadth; each fillet is then wetted and stretched so as to produce an even surface; it is then passed between rollers against a nicely-adjusted knife edge, which shaves it down to a uniform thickness. The fillet is then wound upon a roller, and passed between two guide rollers to a receiving roller above the card-making machine, where the fillet is held fast and is stretched by a clamp. The wire for the teeth is contained on a drum at the side. The action of the card-making machine is as follows:—Two prickers advance, and make two holes in the leather; a pair of sliding pincers next seize the wire, and wind off from the drum a length exactly sufficient for the teeth; a tongue of steel holds this piece of wire exactly in the middle, while a knife advances and cuts it off from that part of the wire held in the pincers. Steel fingers next advance, bend the piece of wire just cut off, and carry it forward to the holes previously made by the prickers. The points of the wire are seized on the opposite side of the leather, and a bar rises up and bends the two limbs, so as to form a knee in each. A pusher then acts from the opposite side, and drives home the wire into the leather, which is then shifted by the guide rollers, and another wire is inserted as before. This machine works so rapidly as to put in 200 teeth every minute, and to complete a length of 20 feet of card in a day. At Messrs. Curtis's factory, at Manchester, the writer saw 90 card-making machines at work in one room. Some of these machines insert the dents in lines across the fillet, at right angles to its length; others insert them in oblique lines. After the cards are completed by these machines they are finished and made true by grinding, and when in use they are ground down from time to time until the teeth are worn out. [See APPENDIX.]

Fig. 639 will explain the action of the cards in disentangling the fibres of the cotton wool, and laying them parallel. If the two cards A and B be moved in opposite directions with a tangled tuft of cotton between them, the fibres will be seized by all the teeth, one card pulling them one way, and the other card the opposite way, until, by repeated applications of the cards, the fibres are disentangled and laid in parallel lines, each card taking up and retaining a portion of the cotton. All the cotton may be got upon one card by reversing the position of the two, and placing them as in Fig. 641, in which, by drawing the upper card *a* over the lower *b*, the teeth of the latter can offer no resistance, and it will give up its cotton to the upper card.

Fig. 638.

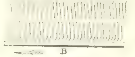

Fig. 639.

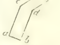

Fig. 640.

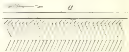

Fig. 641.

To apply these principles to the carding engine given in section, Fig. 643. The main carding cylinder, A, is formed of parallel segments of mahogany, screwed upon rings of cast-iron fixed to the central shaft. Each of these segments has nailed to it a length of card leather, or card-cloth, equal to the width of the main cylinder. A portion of the upper part of this cylinder is covered with parallel segments of mahogany, B, called *card-tops*, the ends of which rest upon the heads of adjusting screws projecting from the side framing, and they are kept in their places on the frame by pins passing through their ends. Their concave surfaces are covered with a narrow fillet of card-leather. The small rollers D, E, F, G, called *urchins* or ***squirrels***, are covered with card fillets wound spirally round each from one end to the other. The engine is fed by means of a pair of fluted iron rollers, *h*, pressed together by a screw, *c*; *h* is a feed-board, along the surface of which the fleece, unwound from the lap roll, I, by the acting roller, K, advances to the feed rollers. The first roller-card, D, called the *licker-in*, turn with much less velocity than the drum-card, and draws in single filaments from the feed-roller. These filaments are immediately stripped from it by the large cylinder, A, to be again teazed out by the teeth of the second roller, E, which moves still more slowly than D, thus serving to pick off the knots from the drum. These knots being carried round by the roller, are again presented to the cylinder, D, as it revolves nearly in contact with E. The roller D next transfers the teazed out filaments to the drum, blending them with fresh ones supplied by the feed-rollers. The tufts, or knots, which escape the action of the first two rollers, D and E, are almost sure to be laid hold of by the fourth roller, G, which is placed closer to the drum, and moves with the same speed as E. The knots caught by G are teazed out by F, which is nearly in contact with it, but revolves at a quicker rate, but not so fast as the surface of the drum. The loosened fibres are thus seized by F, and once more transferred to the drum, whence they proceed, and receive a second teazing from the roller G. Any knots which still remain are arrested by the first flat top cards, and held there till they are disentangled by the rotation of the drum. These flats are occasionally taken out and cleaned, and the first flats require more frequent cleaning than the others. After the filaments of cotton have passed by the flats, they lie in nearly parallel lines among the card teeth of the drum, and from this they are removed by a smaller drum card, which is covered spirally with fillet cards, and is called the *doffer*. This doffer, L, turns slowly in contact with the drum, and in an opposite direction, and thus becomes covered with a fine fleece of cotton,[1] which is removed from the opposite side of the cylinder by the vibrating action of the doffing knife M, Fig. 614. This consists of a blade of steel toothed at its edge like a fine comb, and it is made to strike down, by means of the crank T and the upright rods *p p*, with a rapid motion tangentially over the points of the cards. In this way a fine transparent fleece is removed, equal in breadth to the length of the card on the doffer, but its breadth is immediately contracted into that of a narrow riband, by being passed through the funnel, *i* Fig. 613. This riband is called a *carded end* or *sliver*, and it is consolidated by being passed between three pairs of iron rollers, *k*, *l*, *m*: the bottom rollers of *k* and *l* are finely fluted, or channelled, and the top ones are covered with two coats, the inner of flannel and the outer of leather. The upper rollers are pressed upon the lower ones by weights, *z*, hung upon their axes. We here first observe the effect of the beautiful invention of passing the cotton between pairs of rollers moving with different degrees of speed. The pair of rollers, *l*, moves faster than the pair *k*, the effect of which is to draw out and straighten the filaments. The card end, after being spread by the first two pairs of rollers into a flat riband, is passed through a vertical slit in a plate N, situated between the second and third pairs of rollers, which gathers it up into an elliptical sliver; it is next drawn through two smooth rollers, *n*, which are slightly pressed together, and lastly it is received into the tin can, *o*, in the shape of a spongy, slightly coherent sliver. In fine spinning the cotton passes through two carding engines; the first, which is coarse, is called a *breaker-card*, and the second, in which the teeth are set finer, a *finishing-card*. A number of cardings from the breaker card are united

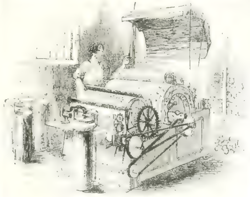
Fig. 612. CARDING ENGINE.

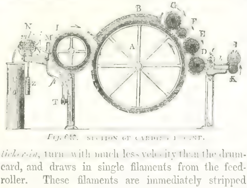

Fig. 613. SECTION OF CARDING ENGINE.

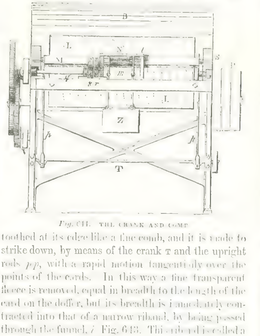

Fig. 614. THE CRANK AND COMB.

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[1] The drum revolves with a surface velocity of from 20 to 30 times quicker than the doffer, according to the nature of the cotton.

together at the edges, by passing them between the steel rollers of a lap-machine; the new lap thus formed is wound upon a cylinder, from which the finishing card is fed.[1]

The inventor of the carding-engine is not known with certainty. It appears, however, that in 1748, Lewis Paul patented two different machines for carding, in one of which the cards were arranged on a flat surface, and in the other on a drum. The cards were arranged parallel to each other and to the axis of the drum, a space being left between every two cards. The wool was put on by hand, and the cardings were taken off separately by a movable comb, the spaces between the cards regulating the substance of each carding. By this method the machines had to be stopped every time the cardings were taken off, and then had to be joined end to end to form the perpetual carding. The machine was not generally known and adopted in Lancashire for more than twenty years after the date of the patent. One of the first improvements was to fix to the machine a revolving cloth or feeder, on which a given weight of cotton wool was spread, by which it was conveyed to the machine. Arkwright further improved this by rolling up the feeder with the cotton spread upon it, as already explained, and allowing this gradually to unroll to feed the cylinder. Another improvement brought off the carded wool in a continuous fleece, forming a uniform and perpetual sliver. The doffer, which strips the wool from the large cylinder, turned off a carding of no greater length than that of the cylinder; but it was found, that by entirely covering the doffer with narrow cards, wound round in a spiral form, without having any spaces, the wool might be brought off in one unbroken fleece. But the method of stripping off the wool from the doffer was attended with many difficulties, which were at length overcome by the invention of the crank and comb, the merit of which has been ascribed by some to Arkwright, by others to Hargreaves, the inventor of the jenny. Those who defend the claim of the former say that it was communicated to Hargreaves by one of Arkwright's workmen, who chalked out a sketch of it upon the table of a public-house. The carding-engine has scarcely been improved since Arkwright's time, and the work performed by it is very satisfactory. At one end of the engine we see the cotton in its tangled knotted state, the fibres lying in every direction; at the other end we see stripped from the doffer by the crank and comb the beautiful filmy web, in which all the filaments are arranged nearly parallel, or are tending to arrange themselves in parallel lines in the sliver.

DRAWING and DOUBLING.—The object of these operations is by means of revolving rollers to draw out and elongate the spongy slivers or ribands, produced by the carding engine, to straighten the filaments, and to lay them as parallel as possible. The drawing frame also serves to equalize the different qualities of the cotton, by uniting many slivers into one, whereby their mutual defects are corrected, and the sliver is attenuated preparatory to the next process. In the carding engine, many of the filaments are doubled, but they are all unfolded in the drawing. The drawing frame consists usually of three pairs of rollers, the upper one of each pair being covered with smooth elastic leather, the under ones fluted longitudinally; and by the pressure of the two, the slenderest filaments are seized and pulled out. The under rollers are driven by wheel-work with varying degrees of velocity, and they carry round by the friction of the flutings the upper ones, which are pressed upon them by a considerable weight. In Fig. 646, *a b c* are the under rollers; *a′ b′ c′* the upper ones; the former turn in brass bushes fixed upon iron bearings. The front roller beam is fixed, but the bearings of the two other rollers admit of being shifted in grooves, so as to make these rollers approach to or recede from each other and from the front roller until their respective distances are adapted to the length or staple of the cotton wool which is being operated on; the bearings are then made fast by screw-nuts, acting on the edges of the slits in the slide bearers. The length of the top rollers is equal to that of two fluted portions of the under rollers, and in the middle of each top roller *a′ b′ c′*, is a smooth neck, on which the brass bushes *e f* rest, suspending weights by means of the wires, *h h′*. The two back rollers, which turn most slowly, are usually pressed down by one common weight, and the front roller by a separate weight. The three top rollers are covered

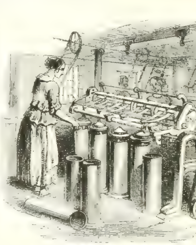
FIG. 645.—DRAWING FRAME.

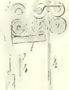

Fig. 646.

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[1] Card sheets are distinguished by the number of wires in each breadth of [illegible] inches for the drum, and 2 inches for the top cards: the number of wires per inch counted in the length of the sheet leather are called *crowns*. For the preparation of yarns below 36 hanks in the pound, the cards have [illegible] wires per sheet for the drum; the first, second, and third tops 20; the middle tops [illegible]; and the last 28. For the preparation of yarns of 100 and above, the cards have from [illegible] to 100 wires per sheet for the drum, and so on in proportion.

with a mahogany bar faced below with flannel, for the purpose of wiping off any stray filaments which may adhere to the top rollers. A similar bar, *l*, faced with flannel above, is made to bear, by a light weight *m*, upwards against the two front rollers, *b* and *c*, to wipe off stray filaments. The cord or wire from *m* is seen going over the neck of the roller *c*, and down again for the purpose of suspending the mahogany wiper bar *l*. G, Fig 648, shown separately in Fig. 647, is a smooth curved plate of brass or tin plate, with a channelled surface, along which the slivers *n n*, from the respective cans at the back of the machine, are guided to the rollers. From 3 to 6 slivers are thus brought together, and united upon one fluted portion of the under rollers, or the channels may be made to converge as in Fig. 647, by which several slivers are guided in upon one fluting. The sliver, thus doubled six-fold, is drawn out in passing through the rollers into a uniform sliver of greatly increased length. Two such slivers are usually again brought together in a funnel I, and delivered by the two smooth rollers K K, into a can in front of the machine. (Fig. 645.) In some cases, one of the slivers, just after its delivery, is turned back over the smooth roller K′, and united with the slivers entering the funnel of the adjoining drawing. The object of this funnel and pair of smooth rollers, is to collect into a compact riband the cotton filaments which were previously spread out broad and thin by the drawing rollers *a*, *b*, *c*.

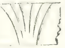

Fig. 647.

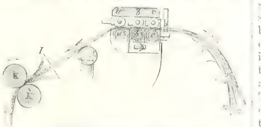

Fig 648. DRAWING AND DOUBLING.

The action of the drawing-frame is thus further explained by Dr. Ure:—"Were the surface velocities of the three rollers *a*, *b*, *c*, Fig. 648, equal, the card ends, *n n*, after gliding over G, would pass through to the funnel I unchanged. But the velocity of *b* and *c* being greater than that of *a*, the former will deliver a greater length of riband than they receive from the first, or than this receives from the cans. Under these circumstances, the only result must be a proportional extension of the riband or sliver in the intermediate space between *a*, *b*, and *c*, and an approximation of the filament to rectilinear parallel directions during the stretching process. The rollers are so adjusted, that the drawing takes place chiefly between the first and the third pair; in fact, the middle pair can have no influence in the drawing power beyond the difference of the first and third. The intervals between *a*, *b*, and *c*, or between their lines of contact with the upper rollers, should be in all cases calculated, so that they may exceed the average length of the cotton filaments, and so that these filaments may not be placed in danger of being torn by the third pair pulling, while the second pair has a firm hold of their other ends. Between these two pairs of rollers, however, where the principal drawing occurs, the distance should be no greater than is absolutely necessary to render the drawing out of the fibres along side of each other practicable without their disruption; this adjustment being requisite to the uniformity of the drawing operation. Were that interval too great, it is obvious that a sliver, in running through the rollers, would become attenuated in the middle point between them, or might possibly break asunder; hence the drawing will be the more regular, the more nicely the interstitial space between the rollers is adapted to the length of the staple of the cotton. When one end of a filament, after being ushered in by the back rollers, is laid hold of by the second or middle pair, it is twitched suddenly forwards in a very gentle manner, so as to stretch it very slightly; but when advancing, it is seized by the front pair, and is more forcibly pulled at one end, while it is held at the other by the friction of its fellow filaments, detained by the slower rollers; the distances of the different rollers being previously adjusted exactly to the average length of the staple. The sliver thus drawn with multiplied doublings, acquires a regularity of texture which, if not impaired in the subsequent processes, ensures a level yarn to the cotton-spinner. Were the drawing of a single sliver attempted to be continued until the suitable parallelism of its filaments were effected, it would ere long become an impossible operation on account of the excessive attenuation of the riband. This inconvenience is obviated by the very simple method of associating, at each repeated drawing, several of the formerly-drawn slivers together into one riband; this is the process called *doubling*. It is an accurate imitation of what happens when we take a little cotton wool between the fingers and thumb of one hand, and draw it out with those of the other, at each turn laying the two parcels parallel again. The doubling secures the great advantage of causing the unequal parts of slivers to correct one another, and to produce finally a very uniform riband."

The following details will give some idea of the elaboration of the card ends from the commencement. Suppose 10 card ends to meet and unite in passing through the first pair of rollers, whereby they are all reduced to one sliver; the second pair reduces every inch of this compound sliver into about 2 inches, and the third pair of rollers extends these 2 inches into 10; so that the result of this first operation, is a sliver of the same thickness as one of the 10 card ends, but of 10 times the length. Next let us suppose that 10 cans filled with the compound sliver are passed on to a second drawing-head, and the 10 *drawings* are again doubled and drawn out into one; that 12 of these are doubled and drawn out at a third head; that 12 of these are doubled again and drawn out at a fourth head; and lastly, that 6 of these are doubled and drawn out at a fifth head.

Now, collecting all these numbers together, it will be seen that before a thread is attempted to be spun, the fibres are placed parallel to each other 86,400 times; for 10 × 10 × 12 × 12 × 6 = 86,400. The drawing is carried on to this extent only in fine spinning. For coarse numbers, 6 card-ends are usually passed through the first drawing-head, and formed into one riband; 6 of these ribands are again formed into 1; 6 of these make a third sliver, and 5 of these are passed through the last drawing-head. Thus the doubling of the fibres of the cardings has been multiplied 6 × 6 × 6 × 5 = 1080 times.

We have been thus minute in noticing drawing and doubling, as the quality of the yarn depends greatly on the success of the process. It is stated of Arkwright, the perfector if not the inventor of the process, that when any defects appeared in his yarns, he told his people to look to their drawings, for if they were right, everything else would be so too.

The drawing-frames require constant watching to supply the place of the cans that are emptied with full ones, and also to mend the feeding sliver ends whenever one of them breaks. This duty is performed by a young woman named the *drawing tenter*. The machine is stopped instantly by moving a lever, which throws the strap from the working or fast pulley upon the loose pulley. The receiving can is made to contain an increased quantity of sliver, by means of a cylindrical plunger which falls at intervals into it. The sliver is also made to coil up regularly in the can in a compact form, without being at all stretched.

ROVING.—By the process of drawing, the cotton wool has been formed into a loose porous cord, the fibres of which are arranged in parallel lines. This cord is much too thick to be spun into yarn, and it is too tender to be reduced in size by drawing merely: a slight twist is therefore put into it, and this, by condensing the fibres, allows the drawing to be proceeded with. This, in fact, is the commencement of [illegible], is little [illegible] than a combination of drawing and twisting, and it is called *roving*. The roving machine, which was introduced by Arkwright, resembled the drawing-frame. It consisted of two pairs of drawing-rollers, Fig. 649, for extending the slivers, of which two were generally doubled and united, and the sliver, after leaving the drawing-rollers, was received into a can, which was made to turn rapidly round; and this, by giving a slight twist to the sliver, formed the *roving*, and distributed it in a coil within the can, from which it was removed when full by a door left open as in the figure. The process was thus far successful; but it was necessary for the next operation that the roving should be wound upon bobbins, and this was done by girls, by the aid of a simple machine, called a *winding-block;* but in handling the delicate cord it was scarcely possible to avoid injuring it, so that the quality of the yarn suffered. This led to the introduction of the *Jack-frame* or *Jack-in-a-box*, in which the twist was given by the revolution of the can as in Fig. 650; but instead of being coiled up within it, the roving was wound upon a bobbin *b*, lying upon a carrier cylinder *c*, made to revolve by wheel-work, not shown in the figure, at such a rate that its surface velocity corresponded with that of the front drawing-roller. A guide-wire *g* was made to move backwards and forwards in front of the bobbin, in order to distribute the roving equally upon it. The Jack-frame was superseded by the *bobbin-and-fly-frame*, which, after a large number of improvements and modification by various inventors, may now be considered as the roving-machine of the cotton manufacture. We will first endeavour to explain the principle of this very complex machine, and then to give the details of the mechanism by which it is carried out. The chief difficulty in this class of machines arose from the soft tender nature of the roving, and the nicety required to wind it on the bobbin at exactly the same rate that the front pair of rollers sent it forth.

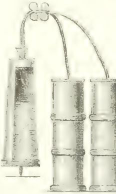
Fig. 649.

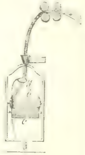

Fig. 650.

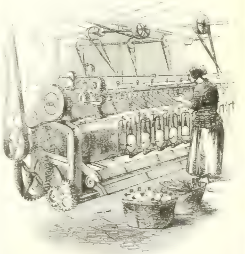
Fig. 651. BOBBIN AND FLY FRAME.

The bobbin-and-fly-frame has to perform two essential operations: *first*, to twist or spin the sliver into a roving, and *secondly*, to wind the roving in a regular and equable manner upon the bobbin. Fig. 651 is a pictorial view of a portion of the machine, which is of considerable length. The bobbins containing the sliver are mounted upon a shelf called a *creel*; from these bobbins the sliver is passed through a set of drawing-rollers mounted on a beam similar to those used in the drawing-frame. Before the sliver enters between the back pair of drawing-rollers, it is led through between two guides fixed upon a wooden bar, which has a very slow lateral transverse motion, so as to shift the sliver alternately to the right and left about three-quarters of an inch, in order to prevent the leather covering of the top rollers from being indented or grooved by the slivers passing constantly over the same line of surface. After leaving the front pair of rollers, the sliver is received by the spindles, which are arranged in two rows, for economy of space, each spindle in the back row standing opposite the interval between two spindles in the front row. One frame may contain 30, 60, and even 120 spindles. At the lower ends of the spindles are small bevel wheels, *g'*, Fig. 652, driven by others, *f'*, fixed on horizontal shafts which go from one end of the machine to the other; *g g*, Fig. 654, is the flyer or fly, one arm of which is made hollow, for the purpose of containing the roving, the other being a solid rod, the only use of which is to counterbalance the former, and prevent its flying off or getting loose upon the spindle, on the conical summit of which it is pressed after a full bobbin has been removed and an empty one put in its place. The bobbin, Fig. 655, is a simple wooden tube, upon which the roving is wound, so as to produce conical ends, as in Fig. 656, by shortening, after a certain period in the winding-on, the extent of the up-and-down motion of the bobbin, which is given in order to distribute the roving equally and compactly over the bobbin. This object is further assisted by the steel finger of the fly, Figs. 653, 654, over which the roving is twisted, and which winds it on the bobbin with a certain pressure. Now, supposing this system to be in motion, the bobbins on the creel give out the sliver to the rollers; these, after extending it by drawing, pass it down to the spindles, which by their rapid rotation twist or spin it into roving, which roving is then wound upon the bobbins which surround the spindles. It is evident that as the roving is always winding from the lower end of the flyer, it is necessary that the bobbins ascend and descend as they revolve, so that the roving be laid evenly and smoothly upon them. This rising and falling motion is produced by the gradual ascent and descent of the copping-board, on which the bobbins rest, by which means every coil of roving falls close to but not upon the former coil, thus disposing it regularly throughout all the length of the bobbins; and when the latter have descended to the lowest point, they gradually rise again, then fall, and so on, till they are filled, and renewed by the tenter-women, whose business it is to supply other bobbins, and to unite any of the rovings that may separate or break. Now it is evident that as the bobbins become filled with rovings, and the circumference of each bobbin increases, it requires to have a gradually decreasing velocity, or, in other words, it is necessary after each ascent and descent of the bobbin that its speed be made proportionally slower, in order that the quantity wound up in a given time or in any given number of revolutions may be the same; for unless this precaution be attended to, the roving would not be of the same quality throughout: it would be slightly thicker when the bobbin was nearly empty, and would go on diminishing in thickness as the bobbin became covered; and this stretching force, not having the equable action of the drawing-rollers, would injure the roving. This change in the velocity of the bobbin is produced in various ways; one of which is by means of two conical barrels, Fig. 657, of the same dimensions, but placed with the larger end of one opposite the smaller end of the other. One of these barrels, being driven with a uniform motion, communicates motion to the other by an endless band, which, by being shifted towards either extremity, varies the motion of the other barrel. The belt or strap remains equally tight in every part, for the one barrel increases in diameter exactly as much as the other decreases. From the second barrel motion is conveyed to the wheels which work the copping-bar. These alternate cones form an elegant method of changing the velocity

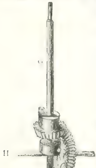

Fig. 652

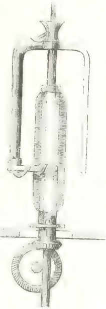

Fig. 653.

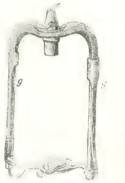

Fig. 654.

Fig. 655.

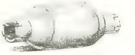

Fig. 656.

of motion when this is required to be gradually and uniformly accelerated or retarded. It is obvious that if the axis of one cone, A, Fig 657, have a uniform motion, its surface must move with varying degrees of velocity; and if motion be communicated from the surface of A to that of B by means of the belt, such motion can be accelerated or retarded at pleasure by causing the belt to be moved along by means of a guide, or the motion may be kept constant if the guide be kept stationary.

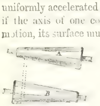

Fig 657.

There are two sets of bobbin-and-fly-frames in common use, called the *coarse* and the *fine*, or the *first* and the *second roving-frames*; they are the same in principle, but the first has fewer spindles, and is fed with slivers from cans filled at the drawing-frame and placed at the back of the machine. The second roving-frame is fed with rovings, or, as they are sometimes called, *slubbings*, from bobbins filled at the first frame, and they are arranged on upright skewers fixed in a shelf or *creel*, placed behind the roller-beam. The roving from these bobbins passes through wire-eyes, to prevent it from being torn obliquely from the bobbins. In the coarse roving-frame the top of the machine behind the rollers is covered with a smooth plate, upon which the sliver glides from the cans toward the rollers. A rod stretches along over the machine, having at its extremity a guide for pulling the strap which drives the fast or steam-pulley: this rod, therefore, serves, when slid to the right or to the left, to put the machine into or to throw it out of gear, as the tenter requires in the course of the work, at whatever part of the frame she may happen to be.

These arrangements being understood, it will be seen that the twisting of the sliver is effected by the revolution of the spindle and fly, but the quantity of twist depends on the ratio between the surface-speed of the front delivering-roller, Fig. 651, and the revolutions of the spindle. The winding on of the twisted roving upon the bobbin is effected by giving to the bobbin such a velocity, that the difference between the motion of the surface of the bobbin and the motion of the delivering end at the arm of the flyer shall equal the surface-motion of the roller, or the supply of the sliver. The spindle and the bobbin being driven by different movements, and at different rates, the winding is effected either by making the bobbin revolve a little faster than the spindle, or the spindle faster than the bobbin. If, for example, the bobbin revolve 50 times while the spindle only revolves 40, 10 turns of the bobbin will have nothing to do with the winding; but there are ten turns of the bobbin above those of the fly which will perform the winding. Hence the 40 turns of the spindle produce twist, while the 50 turns of the bobbin produce 10 coils of the roving upon its barrel.

In the coarse bobbin-and-fly-frame it is usual to make the spindle revolve quicker than the bobbin, and in the fine frame to make it go slower. Dr. Ure places this matter in a clear light by the following examples:—"Suppose 45 inches of roving are to be wound upon a bobbin whose barrel is $4\frac{1}{2}$ inches in circumference: 10 turns will be required. Suppose these 45 inches to receive 30 turns of twist: the spindle and fly must give these 30 turns during the winding on of the roving. If the bobbin, therefore, be $1\frac{1}{2}$ inch in diameter, it must make 10 turns for the winding on, and 30 turns in following the spindle; in all, 40 revolutions. If the bobbin be 3 inches in diameter, or 9 in circumference, it must only make 5 turns to wind on the 45 inches: these 5 turns added to the 30 turns required for twist make 35 revolutions; and so on for any other dimensions of the bobbin. Hence, the number of turns of the bobbin, plus the number of turns of the spindle, is a quantity always inversely as the diameter of the bobbin. The motion of the bobbin and spindle is simultaneous, and in the same direction, with a difference varying more or less, according to the varying diameter of the bobbins. But suppose for a moment the spindle to be stationary: then the bobbin must turn with such a velocity that it will wind on the roving just as fast as the front rollers deliver it. This roving comes forward at a uniform rate; but the bobbin, continually increasing in diameter, should turn with a velocity uniformly retarded. Motion being given to the spindle, it is evident that when the winding is forward, as in the fine fly-frame, we must deduct from the rotation of the bobbin, required for winding on the roving, that of the spindle, required for the twist; for the circumference of the bobbin being $4\frac{1}{2}$ inches, 10 turns take up 45 inches. These 10 turns deducted from the 30 made by the spindle leave only 20 turns for the effective speed of the bobbin; or, if the circumference be 9 inches, 5 turns will take up the 45 inches, if the spindle be at rest, but if the spindle make 30 turns for twist, the effective speed of the bobbin will be $30 - 5 = 25$ turns. Hence, for the fine bobbin-and-fly-frame the number of turns of the spindle, minus the number of turns made by the bobbin in the same time, is a quantity inversely as the diameter of the bobbin. In the coarse frame the bobbin should move faster than the spindle, and its speed should go on diminishing; while in the fine frame the speed of the bobbin is less than that of the spindle, and it goes on progressively increasing.

In the coarse roving-frame the spindles revolve on an average 750 times per minute, turning off for each spindle 400 inches per minute, or $666\frac{2}{3}$ yards per hour. In the fine frame there is more twisting power, and this produces on an average $533\frac{1}{3}$ yards per hour. In the coarse frame the sliver is elongated from 4 to 6 times, the principal draught of $1\frac{1}{2}$ being between the front and middle rollers, and the remaining $1\frac{1}{2}$ between the middle and back rollers.

For fine spinnings the rovings are weighed on the bobbins by a quadrant beam, and distributed according to their respective weights into 5 numbered baskets. In some coarse spinning mills only one carding, one drawing, and one roving are employed for manufacturing the yarn used for the cheapest calico.

Such is a general account of the bobbin-and-fly frame. The reader who is interested in the study of machinery, will find it an instructive exercise to make himself master of this complicated machine, which he will be able to do with the assistance of the accompanying steel engraving, and the following wood engravings and description, which have been prepared for the editor by his friend Mr. Hatcher.

We may consider that there are three things to be accomplished by this machine:—First, the roving has to be reduced in size, and consequently elongated. Secondly, it is to have a certain determinate number of twists given to each foot of its length. Thirdly, it must be coiled evenly round the bobbin, into the shape shown in Fig. 656.

The steel engraving, which we shall refer to as the plate, represents a back view of the mechanism of the bobbin-and-fly machine, and Figs. 658, 659, 660, represent a section and details of the same, similar letters being used in all cases to the same parts. Only a few of the spindles and rollers are drawn in the plate, so that the figure might be as clear as possible.

1st. To reduce the roving.—A strap from the engine shafting of the factory drives the main shaft B. This shaft by means of the speed-wheel 1, and the carrier-wheel 2, drives the wheel 3, and shaft C, which at its extremity carries a wheel 4, driving a larger wheel 5. This last is keyed on the shaft of the bottom front drawing rollers. It also carries a toothed wheel 6, which acts, by means of the carriers 7 and 8, on wheel 9, fixed on the shaft D of the lower back rollers, *d d d*. By changing the various wheels of this train, between Nos. 4 and 9, for which facilities are afforded in the construction of the machine, any relative degrees of velocity can be given to the front and back rollers, so as to draw or attenuate the roving just so much as may be required. Suppose, for instance, the back rollers were 1 inch in diameter, and made 60 turns per minute, and the front pair were 1¼ inch in diameter, and made 180 turns per minute; then the back pair will deliver out $3.14 \times 60 \times 1 = 188.4$ inches per minute, which by the greater speed of the front rollers will be lengthened to $3.14 \times 180 \times 1.25 = 706.5$ inches. So that the roving will have its length increased 3¾ times, and its thickness reduced in the same proportion.

2d. To give the roving thus drawn out a certian determinate degree of twist. The shaft B carries a bevel wheel 10, which by means of the wheel 11, shaft E, and wheels 12 and 13, drives the long horizontal shaft F F. This shaft extends along under the cast-iron beam *f f*, and carries a series of small bevelled wheels *f′ f′*, which drive the upright spindles G G G, by means of small wheels *g′ g′* keyed upon these spindles. See Fig. 652. The spindles revolve independently within the disks and collars of the bobbins, on the beam *h*, and at their tops they carry the flyers *g g g*. Hence the flyers derive their motion from the same shaft B, which gives movement to the drawing rollers, and therefore the number of revolutions made by the flyers in any given time, will always bear such a constant ratio to the speed of the drawing rollers, as the attendant may by his arrangement of the wheels 4, 5, 6, 7, 8, 9, have determined upon beforehand. If, therefore, in one minute, or while the front drawing rollers deliver out 706½ inches of roving, the spindles with their flyers make 1,300 revolutions, the roving will have rather more than 1¾ twists in each inch of its length. This is the usual proportion for the first or coarse machine. We repeat, (as it is important to bear this in mind,) that the velocity of the spindles bears always a certain predetermined ratio to the delivering speed of the drawing rollers, and that therefore the twist which the roving receives is always the same, throughout the piece, that has been fixed upon at its commencement. The rate of winding on to the bobbin, or the varying actual rapidity of the whole machine, cannot alter this ratio between delivery and twist.

3d. The coiling of the twisted roving upon the bobbin. We must here consider how we should proceed to wind the roving, so as to produce an even bobbin or "cop" of the shape shown in Fig. 656, and with no overlapping or irregularity in the laying on of successive coils.

First, then, we have seen that the bobbin must be carried regularly up and down within the flyer, as the roving winds on, at such a speed that each turn may lie evenly by the side of the preceding one, neither overlapping nor leaving a vacant space. This motion of the bobbin or "traverse" must continue steadily upwards, till one layer has been put on from top to bottom of the coil; and must then be suddenly reversed and continued steadily downwards, till the second layer has been put on, then again reversed for the third layer, and so on. Secondly, as each successive layer increases the effective diameter of the bobbin, the speed of revolution of this bobbin must be altered after each layer is completed; so that the rate of taking up of the bobbin may remain the same, and its surface velocity be always equal to the rate of delivery of the front rollers. Now suppose the bobbin to be 1¼ inch in diameter, or just equal to the front drawing rollers, then while these are delivering off 706½ inches of roving, the bobbin must move so as just to wind up this quantity, which will give evidently 180 entire coils. But while this 706½ inches is being delivered off, the flyer (in order to give it the right amount of twist,) is making 1,300 revolutions. We want the winding-up action, which is equal to the difference between the speeds of the flyer and of the bobbin, to equal 180 turns in this time. Therefore the bobbin must revolve at such a speed as would carry it through $1300 + 180 = 1480$ revolutions, in the same time that the flyer is making 1300. Now if each layer of roving increase the diameter of the bobbin by $\frac{3}{10}$ths of an inch, then we shall have for the second layer of roving:—

Circumference of bobbin $= 3.14 \times (1.25 + .30) = 3.14 \times 1.55 = 4.867$. Therefore the number of turns to be made by the bobbin, to take up the second 706½ inches of roving $= \frac{706\frac{1}{2}}{4.867} = 145$ nearly. So that while the flyer continues to revolve at a speed which would carry it through 1300 revolutions in one minute, the bobbin must now revolve so as to make 1300 + 145 = 1445 turns. Similarly we find that for the third, fourth, and fifth layers, the bobbin must revolve at such a speed as would make the ratio of its velocity to that of the flyer, as 1423 : 1300, 1405 : 1300, 1391½ : 1300 respectively. These numbers express ratios of velocity only, not that such numbers of turns must be actually made by one and the other before the speed changes; for the speed must change directly each layer is completed, whatever be the number of turns in it. It will also be evident that as the diameters of the bobbins, and consequently the quantity of yarn contained in each coil increases, the traversing or up and down motion of the bobbins must be slower. Were it not so, as the bobbin revolves more slowly in proportion to its speed of traverse, the yarns, instead of being laid closely together, would form an open screw-like coil. Thirdly, as the full cop must have its ends tapered, as in Fig. 656, to prevent any risk of the rovings slipping off, it is clear that each successive traverse of the bobbin must be shorter than the one preceding. Fourthly, as the bobbin when full will only just enter within the flyer arms, the action of the machine must be stopped with certainty, directly it has filled a set of bobbins. We now proceed to describe how these requisite adjustments are attained.

First,—to produce the traverse motion. The bobbins rest on a long beam or inverted trough of iron *h*, termed the "copping bar," or "copping rail." This is not fixed in the machine, but is fitted with slides to the end frames Z Z, and with guides to the upright rods *y y*, so as to be capable of moving up and down, through a distance equal to the length of the bobbins. Its weight is partly counterpoised by masses of cast-iron, suspended from it by chains passing on the pulleys X X. The chains and weights are omitted in the figures, to avoid complexity, but their action will be readily understood. The spindles G G pass through this copping rail without touching it, so that the small disks on which the bobbins rest, which are made to revolve by the bevelled wheels fixed upon the long dotted shaft H, can continue to revolve while travelling up and down the spindles. The shaft C before mentioned as driving the rollers, carries a drum, 15, from which a strap passes to the tin-plate cone, 16; a wheel 17 on the shaft of this cone, drives, by a second spur-wheel 18, the shaft K, and this by the bevel-wheels 19, 20, turns the shaft L, carrying at its end the bevel-wheel 21. This last wheel is placed between two facing bevel-wheels 22, 23, and it is evident that when engaged with one of these it will drive the shaft M in one direction, when engaged with the other it will drive it in the contrary direction. The pinion 24, at the end of shaft M, works in the wheel 25 and drives the shaft N, which carries pinions 26, 26, working in racks, Fig. 658, fixed to the copping rail; so that when the shaft M is driven one way it causes the copping rail to rise, when driven the other way it draws the rail down. The copping-rail has attached to it a slot-piece *i*. In this slot, a pin projecting from the circular end of the sliding bar V, works, and this sliding bar when raised lifts the tumbling bob or loose weight T by the pin v^1; but as soon as the copping-rail has attained a certain height, (raising the tumbling bob as it goes,) this bob having come to the vertical position tumbles suddenly over to the left, and in so doing slides the bolt U to the left, which pulls the bevel-wheels 22, 23, also to the left, by the rod *u* attached to a loose collar connected with the wheels. This brings the wheel 23 into gear with pinion 21, and instantly reverses the motion of the shaft M. Consequently the copping-rail moves downwards, again raising the tumbling bob, but now of course by the sliding lever V bearing against the pin v^2, until the bob tumbles over to the right, and again reverses the motion of the rail by sliding the bevel-wheels to the right. The pins v^1 v^2 can be adjusted in their circular slot, so as to cause the bob to tumble over sooner, and thus lessen the traverse of the copping beam. The bevel-wheels 22, 23, are of course so keyed to the shaft M, that while moving

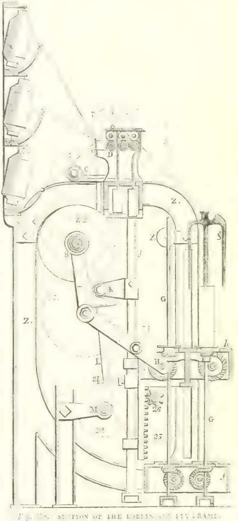

FIG. 658. SECTION OF THE BOBBIN AND FLY FRAME.

freely along it, they still continue to drive it. There is a pin fixed to the long lever S, which moves in the circular slot of the sliding level V, but this evidently does not in any way impede the up and down motion of this lever. The use of the pin will be seen hereafter.

We have now to explain, secondly, how the speed of the bobbin is altered at the completion of each traverse of the copping-beam, so as to equalise the winding on of the roving. We have before mentioned the tin plate cone 16, as driving the shaft K. This shaft carries a pinion 27, gearing into the wheel 28, turning in the centre of the boss, f, of which the use will be shown hereafter. This wheel is connected with the wheel 32, but they both turn loosely on the main shaft B, and have no connexion with it. The wheel 32 drives the long shaft H, by means of the elbow-linked carrier-wheels 33 and 34. On referring to the section, Fig. 658, the use of this elbow-link will be apparent. The bobbins must continue to revolve as the copping-rail carries them up and down, and this is attained by means of the linking of the wheels 33, 34, 35 to 32, so that they remain in gearing while continually rising and falling with the rail. The shaft C is slotted, so that the pulley 15 can slide along it, and yet continue to turn with it; and it is evident that as the pulley slides along, and carries its strap towards the larger end of the cone, this cone will be driven more slowly as its diameter at the driving part is increased. So that while the pulley moves uniformly, it can be made to turn more and more slowly the cone and the train of shafting and wheels which eventually gives motion to the bobbins. A tightening pulley c, which rests against the strap, keeps it always tight enough to drive the cone. At the left hand of the plate is a double rack-piece R, the teeth of which are placed alternately on the top and bottom edges, and which is held by the catches r^1 r_2 from being pulled to the left by the weight q, acting on the top of the long lever S, and by the pin s working in its slot, upon the projecting arm of the rack-piece. When the work commences with empty bobbins, the rack-piece is pulled to the extreme right, so that the catches engage and hold it by the end teeth on the left hand. It will be seen that the lever S is connected by a rod t with the sliding pulley 15, so that any movement of the rack-piece to the left must be accompanied by a corresponding movement of the pulley to the left.

The tumbling bob T at its lower end terminates in a fork, embracing the end of the bell-crank lever W, so that when the bob falls over to the left, at the end of the first upward traverse of the copping-rail, the bell-crank lever is moved to the right, and the upright rod w connected with its short end is jerked down. In so doing, one of two pins at the upper end of this rod lifts the lower catch r_2 from the rack-piece, and this consequently slides to the left (dragging the pulley 15 with it), till its motion is arrested by the upper catch, engaging the next alternate notch of the rack. Here it rests while the copping-rail completes its downward motion, at the end of which the bob tumbles over to the right, and at the same time that it reverses this motion of the rail, also by the bell-crank lever W, and rod w strikes up the upper catch, and allows the rack to slide to the left, till it is caught by the lower catch. As the shaft K drives the bobbins, and also the pinions serving to raise and lower the copping-rail, therefore each escape of the rack, by shifting the band towards the large end of the cone, reduces the speed of the shaft K, and consequently both the speed of revolution of the bobbins and the speed with which the traverse of the bobbins is made; thus providing for the second change which was noticed, as becoming requisite on the progressive increase of diameter of the bobbins.

In this manner, the traverse of the bobbins, the decrease of their speed of rotation, and also of their speed of traverse have been accomplished. We have now to show, in the third place, how the diminution of the lengths of successive traverses is produced, so as to give to the cop its conical ends.

The sliding lever V is not fixed in its centre, but slides in a boss, so as to allow of its length being reduced by sliding the circular head nearer to the centre; the result of which would be, that a smaller extent of up-and-down motion of this lever would make the bob tumble over from one side to the other. When the piece of work is commenced, and the rack-piece placed as far as possible to the right, the long lever S is inclined as much as possible to the right, it being connected with the rack-piece by the pin s passing through this lever and the slotted arm of the rack-piece. In this state the sliding lever is pulled out from its boss as far as possible, and therefore the space through which it must be carried by the copping-rail, before it throws over the bob, is the greatest possible. But each successive escape of the rack-piece draws the lever S over to the left, and this pushes the sliding lever further and further through its boss, by a pin fixed to this lever S, and passing through the circular slot of lever V, so that each successive traverse is rendered shorter than the preceding one, and therefore each layer of yarn or roving is shorter at both ends than the one below it. The ends will thus be rendered conical, as shown in the figures.

In the fourth place, to guard against the overwinding of the cops, it will be observed that the long rod A carries a stirrup embracing the driving-band, so that by this rod the band can be pushed from the fast to the loose pulley, and the motion of the whole machine stopped. On this rod A there is a stop, p, which can be adjusted to any position, and the upright Q, through which the rod passes, is one arm of a bell-crank lever, over the other arm of which the weight q, attached to the rack-piece, hangs; so that the weight would pull the arm Q over to the left, were it not kept upright by a spring-catch q', locking over a small upright piece on the frame of the machine. But when the rack-piece comes to leave the last tooth of its rack, (the bobbins being then just full,) a pin on the upright s' lifts the catch q', and the weight therefore pulls the arm Q over, sliding the long rod to the left, pushing the strap on to the loose pulley, and stopping the whole machine. This is done without any care of the *tenter ;* but we observe that the long rod, extending as it does along the whole length of the machine, allows the tenter, at whatever part of the machine he may be, to stop its motion in a moment, and thus to check any mischief arising from derangements, to allow time for piecing broken rovings, or making other alterations.

The teeth of the racks are set closer together to the right than at the commencement of the rack. This is to accord with the diminishing ratio of the speed of the bobbin to that of the spindle, which is shown by our first calculation of these ratios. The slope of the cone is also duly adjusted, to give, in combination with the diminishing distances of the rack teeth, exactly the proper degree of reduction of speed to the shaft K. But these adjustments, though perfect for any particular kind of yarn, would require modification, when yarn of a smaller diameter, or greater degree of twist, is made. The adjustment for finer yarns is given by the pin *s*, sliding in the slot of the long lever S, by which the effective length of this lever can be increased, and therefore the amount of its motion about its centre for each escape of the rack diminished. As the sliding in of the sliding lever V, and therefore the amount of decrease of traverse and speed of the bobbins, after each layer of yarn, depend on the amount of motion of the long lever about its centre, we have thus the adjustment required for finer yarns. But the adjustment for different twist is made by means of the Equational box, or Differential pulley, *p*, *b*, and Figs. 659, 660. This box consists of two short cylinders of cast iron, *p* and *b*, each enclosing a bevel wheel, 29, 31. Between the edges of these boxes is a spur-wheel, 28, carrying a third bevel-wheel, 30, mounted on an axis forming a radius of the spur-wheel. This third wheel gears into the two other bevel-wheels. Outside of the half-box *p*, and attached to it, is a spur-wheel, 32. The three bevel-wheels are exactly alike in diameter and number of teeth. The half-box *b*, with its wheel, is keyed to the shaft B, and turns with it, but the wheel 28, and the half box *p* with its wheel, turn loosely on the shaft and independently of it. Now, if the wheel 28 be held still, and the shaft B is turned, it is evident that the middle bevel-wheel 30 will act merely as a carrier between 29 and 31, which will turn with the *same speed, but in opposite directions.* If 28 be turned round at the same speed as B, and in the same direction, then the middle wheel 30 has no tendency to revolve on its axis, but acts simply as a pin between 29 and 31, causing 31 to turn with the *same speed as 29, but in the same direction.* These are the extreme cases. The middle case is when 28 turns with half the speed of B, and in the same direction. In this case, 30 merely runs round on 31, and 31 *does not move at all.* Hence, therefore, all possible degrees of motion between absolute rest and a velocity equal that of shaft B, can be given to 31, and therefore to 32, by changes of velocity given to 28, between that of half the speed of the shaft B and that of the same speed as B. Now these changes of velocity in 28 are easily produced, by merely putting a larger or smaller pinion on the shaft K, in the place of the pinion 27. Therefore, as the wheel 32 joined to 31 drives the bobbins, their speed can be adjusted, by this simple change, to have any given ratio to that of the spindles and flyers, whatever be the velocity of these last. Now, if the speed of the flyers were doubled, so as to double the twist of the yarn, the speed of the bobbins must not be doubled also, but must be altered so as to leave the same difference as before between their speed and that of the flyers.[1]

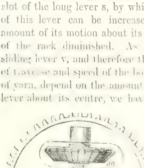

Fig. 659. CENTRE WHEEL OF EQUATIONAL BOX.

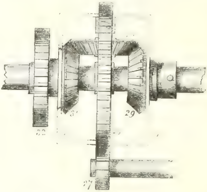

Fig. 660. DETAILS OF EQUATIONAL BOX.

Many of the minor details of the machine, such as the "spring fingers," for assisting the winding of the yarns, the form of the teeth of the bevel-wheels driving the spindles and bobbins, have been necessarily omitted, or only glanced at, in this description.

In fine spinning, two rovings are doubled and passed a second time through the roving frame, where they

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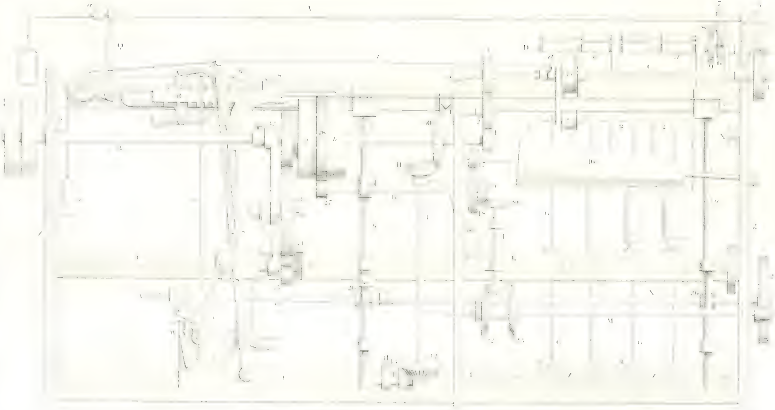
(1) In numbers, this would stand thus. To give double the twist to 706½ inches of yarn, the flyer must make 1300 × 2 = 2600 revolutions in a minute. But the speed of the bobbin must not be double its former speed, for that would be 1480 × 2 = 2960 revolutions per minute, and the taking up in such case would be 2960 − 2600 = 360 circumferences of the bobbin, or 360 × 3.92 = 1411 inches per minute. The *difference* between the speeds of the bobbin and of the flyer must remain the same, and therefore the bobbin must now make 2960—180 = 2780 turns per minute. This adjustment is readily made by means of the differential pulley. We may observe that this pulley (the invention of Mr. H. Houldsworth) seems to give the last degree of perfection to the admirable mechanism of the bobbin-and-fly machine.



receive a further degree of drawing and twist. In fine spinning the rovings are sometimes prepared at what is called the *stretching-frame*, which is a kind of mule-jenny; but the usual plan is to finish the rovings, that is, to spin them into yarn, at one of two machines, namely, the *throstle* and the *mule-jenny*, which are now to be described. The difference between these two machines may be thus briefly stated:—the mule having made a definite length of yarn, the operation of spinning is suspended while the yarn is being wound up upon bobbins or spindles. In the throstle, on the contrary, the yarn is both spun and wound up at the same time. Moreover, the throstle yarn, also called *water-twist* from having been produced at the *water-frame* as already noticed, is smooth and wiry, while the mule-yarn is soft and downy. Throstle yarn is usually employed for *warps* in heavy goods, such as fustians, cords, or for making sewing-thread; mule-yarn is used for the *weft* in coarse goods; and also for warp and weft in finer fabrics.

WATER-TWIST OR THROSTLE-SPINNING.—In the bobbin-and-fly-frame, the roving is twisted only to such an extent as will give it sufficient strength to unwind from the bobbins upon which they are coiled; if they were much twisted, they would resist the action of the drawing rollers of the throstle or the mule. In these two machines, however, the torsion is so increased and the filaments so firmly united, that any further drawing would cause them to break across rather than draw out into downy ends.

The object of the throstle is to draw out the rovings into slender threads, at the same time that it twists them by the rotation of the spindles and flyers; the yarn thus produced is at the same time wound upon bobbins as in the bobbin-and-fly-frame, but with a much smaller outlay of mechanical contrivance, on account of the greater strength of the hard twisted throstle yarn. The throstle consists of two roller-beams, each provided with the usual threefold set of drawing rollers, which, instead of being mounted in fours and sixes upon independent heads, are all coupled together in one range upon each side of the frame. The top rollers are as usual covered with leather, and the roving passes over a guide bar, to which a slight horizontal movement is communicated for the purpose of leading the roving over different points of the rollers, and thus preventing the leather from being chafed by constant pressure on one spot. The machine is usually made double, a row of bobbins, spindles, &c. occupying each side of the frame. The bobbins, filled with rovings, are placed upright upon skewers fixed in shelves in the middle of the frame or *creel*. There are usually from 70 to 150 spindles on each side of the throstle, and they are set from 2½ to 3 inches apart. The spindles on both sides are driven in common, by means of bands from the long horizontal tin cylinder, which extends the whole length of the machine; this cylinder is seen in Fig. 661, and also in section *C*, Fig. 662. On quitting the last pair of rollers, each roving is guided by a little ring or notch of smooth glass let into the frame at *e*, towards the spindles, which revolve with great rapidity, producing by the motion of their flyers a low musical hum, which is supposed to have given the name to this machine.

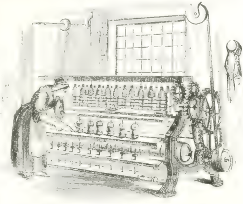


Fig. 661. THE THROSTLE.

The roving, which may now be called *yarn*, passes through an eyelet formed at the end of one of the arms of the flyer, and thus guides the yarn to the bobbin, which revolves round the spindle axis in the middle, between the two prongs of the flyer. Immediately over the spindle, is an eyelet of wire, which serves as a guide to the roving, which is led once or twice round the arm of the fly, and then passed through one of its hooked extremities. The yarn is wound upon the bobbin by a curious

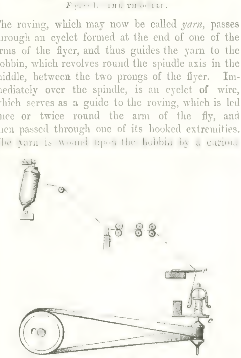


Fig. 662. PRINCIPLE OF THE THROSTLE.

contrivance. The bobbin fits very loosely upon the spindle, and rests with one end upon the copping-rail, *c*. The bobbin is not connected with the spindle, except by the thread of yarn which has to be wound; so that as soon as the flyer is set spinning the thread drags the bobbin after it, and makes it follow the motion of the spindle and fly; but the weight of the bobbin and its friction on the copping-rail, which is promoted by covering the end with coarse cloth, causes it to hang back; and thus the double purpose is served of keeping the thread stretched, and winding it on the bobbin much more slowly than the flyer revolves. The yarn is equally distributed on the bobbin, by a slow up-and-down motion of the copping-rail.

These effects are similar to those produced in the bobbin-and-fly-frame, but in the throstle they are attained by simpler means. In the former machine, the bobbin and the spindle were made to revolve by distinct mechanical movements; in the throstle, the bobbin is made to revolve by the pull of the yarn, which is now sufficiently strong for the purpose; the roving in the bobbin-and-fly frame could not bear such a strain.

The throstle is tended by one young woman and an assistant; they have the care of 140 to 300 spindles in two double frames, and their duties are to mend broken threads, to remove the full bobbins, and to substitute empty ones. This task is called *doffing*, and it occasions on an average the loss of half-an-hour a-day with the common throstle. The full bobbins are collected and carried away in a kind of hamper, Fig. 663, made of buffalo leather, and hence called a *buffalo*. The bobbin of compressed roving, laid on with the spring presser, Fig. 654, will last on the throstle-frame from 4 to 5 days.

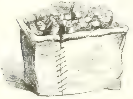


Fig. 663.

The quantity of yarn turned off is about 24 hanks per spindle of 30's twist in 69 hours. In spinning 32's, the front rollers of the common throstle make 64 revolutions per minute, and the spindles, 4,500. It is stated that in spinning 24's, a speed of 80 turns per minute has been given to the front rollers, and 7,000 turns to the spindle.

In some factories, the upper surface of the rollers is wiped and cleaned from loose filaments of cotton, by means of a travelling cone, made of wood, covered with flannel; it is about a foot long, with a base 4 inches in diameter. It is laid loosely on the rollers, and travels by friction in about 17 minutes, from one end of the roller-beam to the other in the direction of its taper end. After completing a journey, it is removed, and a clean one substituted for it.

Several new forms of throstle have been introduced, but our limited space will not allow us to do more than mention the names of the American or Danforth throstle, Gore's patent throstle spindle, Montgomery's patent spindle, &c.

MULE SPINNING.—The object of this operation is to convert the rovings into yarn, and to wind the yarn thus produced upon spindles. This is accomplished by means of a complicated machine called the *mule* or the *mule-jenny*, which consists of four distinct members:—1. Of drawing rollers, consisting, as before, of a number of fluted portions, each of which operates on two parallel threads; 2. A movable carriage, the length of which is equal to that of the roller beam, and containing as many spindles as there are threads to be spun. This carriage admits of being drawn forward through a space of 5 feet in front of the roller beam, and its wheels move upon iron rails, placed at right angles to the roller beam; 3. The head-stock, or machinery which drives the different parts. This is usually placed in advance of the roller beam towards the middle of its length, thus dividing the range of threads into two portions; 4. The creel-frame, erected behind the roller beam, for holding the bobbins of rovings which are to be spun.

Fig. 664 is a cross section of this machine, showing the spinning parts; the carriage is shown by full lines in the position nearest the roller beam, and by dotted lines in the position when fully run out. A is a triple set of drawing rollers, working in heads fixed upon the roller beam, B; C is the creel for holding the roving bobbins in 3, and sometimes 4 rows, one over and behind another. To lessen the friction in unwinding the roving, the lower ends of the bobbin skewers stand in *creel-steps*, or small conical cups of glazed pottery. The creel and roller beam are

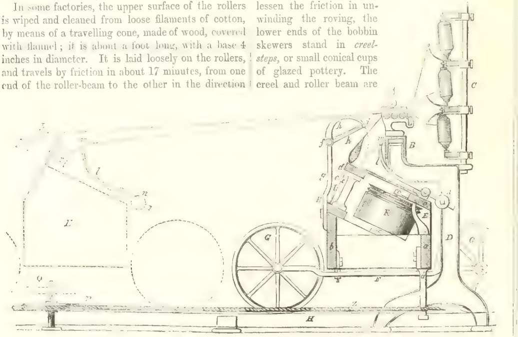


Fig. 664. CROSS SECTION OF THE MULE JENNY.

supported by four pieces of cast iron, as at D. E E is the carriage to which are attached 3 or 4 horizontal bars, F, which rest upon the axis of the wheels, G G. The wheels run upon the railway, H. The carriage is formed of two long planks, *a*, *b*, extending through its whole length, and barred with cross pieces of wood or iron, made fast by screws; there are also diagonal braces, and other contrivances to prevent warping or vibration. Upon these planks is built a frame-work, *c*, *d*, in front of which are fixed the top bushes and bottom steps of the spindles, I. The spindles are set in an inclined position, sloping towards the roller beam, so that in revolving the threads may be twisted round their points without being wound upon their surfaces during the coming out of the carriage; *e* are little pulleys called wharves, fixed upon the under part of the spindles, each at a different height, throughout a range of 8 or 16 adjoining spindles. K is one of a series of drum cylinders, usually made of tin plate, each furnished with two grooves round the upper end for receiving the driving bands. Their smooth sides receive and work the moving bands or cords of two ranges, containing from 16 to 32 spindles. The uppermost cord impels the first spindles of the adjoining two rows; the second cord moves the second spindles of the same ranges, and so on in succession; *f* is a long, slender iron shaft, lying in the bearings, *g*, over the carriage from end to end, and provided with small arms, *h h*, called the *fallers*. These bear the *faller wire*, which serves to depress all the threads from the points of the spindles, as in the dotted lines under *i*, and to bring them upon a level with the bottom of the cop in the act of winding on. The wire being then gradually raised, the thread is duly distributed upon the cop. To assist the spinner in applying the faller wire so as to coil on the yarn with regularity, there is another wire called the *counterfaller;* this consists of lever arms, *l*, with the fulcrum attached to the framework: these arms bear at their points, *m*, a wire which extends horizontally, like the faller, from end to end, but beneath the surface level of the threads. On the other ends of these levers are weights, *n*, which cause the wire *m* to rise so as to balance the threads after they are depressed by the faller wire, *i*, and to straighten them when loose. The carriage is drawn out by a rope, Z, passing round 2 horizontal pulleys, only one of which is shown in Fig. 664, and this is in front of the mule, at the spot to which the carriage comes on completing its stretch: this pulley, P, turns freely upon an upright stud in the floor, and is looped round a bolt, *a'*, attached to the carriage, E. The spindles receive their whirling motion all the time that they go out and in with the carriage by means of a distinct band passing round a twist pulley, provided with 6 grooves of progressively increasing diameter, calculated to vary the whirling velocity of the spindles. This pulley is situated in the head-stock at the back of the mule, not shown in the figure, but an endless band proceeding from it passes over a guide pulley, and then over the top grooves of the drums, K, thus driving all the drums on the right hand side of the carriage; the band then returns round their second grooves, and passes to the drums at the left hand side of the carriage. After driving all the drums there, it returns to the middle of the machine, and passes over guide pulleys to the horizontal pulley, Q, which revolves freely on the same upright bolt with the rope pulley, P, and from thence proceeds to the twist pulley. By this contrivance the band is always of the same length, whether the carriage be in or out, and the drums, K, which work the spindles, are thus continued in motion, at whatever point of its course the carriage may happen to be. Fig. 665 will convey a general idea of the working of these band coils.

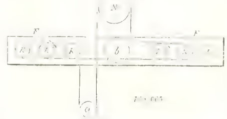


Fig. 665

N is the twist pulley, Q the end pulley, K the carriage drums, and E E the carriage. It will be seen that the carriage can be moved backwards and forwards between the fixed centres of the pulleys N and Q, while the coils of the band continue to move round the drums. It must be remembered, however, that the revolving parts do not lie in one plane as in Fig. 665, but in different planes, the band being conducted over guide pulleys, wherever a change of plane occurs. There are many other parts of this machine which deserve to be further illustrated. The reader will therefore find in the APPENDIX a description of Macindoe's *self-acting mule*, with the working parts represented in two steel engravings. The machine above referred to is not self-acting. Its general working is this:—

While the rollers are delivering the drawn out roving, the steam-engine moves out the carriage with a speed somewhat greater than that of the front rollers; this excess of velocity is called the *gain* of the carriage, and its object is to render the yarn level, by allowing thicker parts of the yarn to be extended while they and the thinner parts are being twisted. While the carriage is being thus moved out, the spindles revolve with moderate velocity, and twist the roving into yarn; but when the carriage has moved out about 45 or 50 inches, according to the fineness of the work, the machine is so contrived that the rollers stop and cease to deliver thread. The carriage is then slowly moved to the end of its course, while the velocity of the spindles is nearly doubled, thereby giving such additional twist (called the *stretching* or the *second draw*) to the yarn as may suit it for the particular purpose for which it is intended; a greater twist being given for warp than for weft, and for bobbinet and book muslin yarns, than for the yarns of softer fabrics. The carriage being drawn out to the end of its course, thereby stretching the threads to the full extent which they will bear without breaking, it is stopped, but the spindles continue to revolve till the requisite quantity of twist is given, and this is regulated by the twist-wheel having completed a certain number of turns. A finger fastened upon the twist-wheel disengages a catch whereby the driving strap is allowed to pass to the loose pulley, and the whole machinery stands still. The spinner then turns a winch-handle acting on a pulley, which moves all the spindle drums at once, and thus causes the spindles to turn a short space backwards, for the purpose of taking off the slant coils from the upper ends of the spindles, and to prepare for distributing the 54 or 56 inches length of yarn just spun properly upon them. This reversing of the spindles is called *backing off.* The spinner then seizes the faller rod with his left hand, and gives the faller wire such a depression as to bear down all the threads before it to a level with the bottom of the cop of yarns which is being formed round the spindle. While the left hand of the spinner is thus employed in the delicate operation of depressing the faller wire, his right hand is slowly turning the handle of the pulley in communication with the spindles, so as to give them a whirling motion in the right direction; at the same time the spinner applies his knee to the carriage, and pushes it in at the proper degree of speed required to supply yarn to the spindles as they wind it on the cop. "Three simultaneous movements must be here very delicately and dextrously performed by the mule-spinner; first, the regulation of the faller or guide wire, continually varying in obliquity; secondly, the rotation of the spindles, perhaps 1,000 in number, at a measured speed; and thirdly, the pushing in of the carriage at such a rate precisely as to supply yarn no faster than the spindles take it up. In fine spinning upon a mule, where nearly 1,000 threads are spun at once, of almost invisible tenuity, the skill and tact required in the operator deserve no little admiration, and are well entitled to a most liberal recompense. In the process of winding on, so as not to break the threads, and in coiling them into the shapely conoid or cop, the talents of the spinner are peculiarly displayed. As the carriage approaches to its primary position near to the roller-beam, he allows the faller wire to rise slowly to its natural elevation, whereby the threads once more coil slantingly up to the top of the spindle, and are thus ready to cooperate in the twisting and extension of another stretch of the mule. Having pushed the carriage home, the spinner immediately sets the mule again in gear with the driving shaft, by transferring the strap from the loose to the fast steam pulley, and thus commences the same beautiful train of operations. It is during the few instants after the carriage starts that the lively little piecers are seen skipping from point to point to mend the broken threads. Whenever it has receded a foot or two from the delivering rollers, the possibility of piecing the yarn being at an end, the children have an interval for repose or recreation, which, in fine spinning at least, is three times longer than the period of employment. The spinner, likewise, has nothing to do till after the completion of the fresh range of threads, when he once more *backs off* the slanting coil, and winds on the *stretch.*" By winding successive portions of thread upon the spindle, the cop, Fig. 666, is formed, which, when sufficiently large, is slid off the spindle, and is sent into the market as *cop-yarn.* A very large portion, however, especially that intended to be dyed or exported, is unwound from the cops upon reels, and then made up into skeins or hanks. Considerable skill is required in giving the cop such a shape as may facilitate the winding off, either in the shuttle or upon the reel. The foundation of the cop, which is first formed, is a double cone, *a, d, b, c;* upon the upper part of this the cone is *built* upwards, so as to form a cylindrical middle part, *a, b, e, f.*

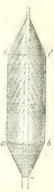


Fig. 666.

One man attends to two mules, guiding in the carriage of one mule by hand, while the carriage of the other is being moved out by the steam engine. The children who join the broken threads are called *piecers* or *pieceners.* There is, also, a child called a *scavenger*, whose business it is to collect all the loose or waste cotton, called *fly*, which lies on the floor, or hangs about the machinery. This is chiefly used in cleaning the machinery. It is calculated that the waste of material from the different machines in spinning cotton amounts to 1½oz. per lb., or nearly $\frac{1}{10}$th. It is the duty of the piecer to join the broken ends of the threads as the carriage moves from the upright frame. The breaking of the threads depends, in some degree, on the temperature, and the state of the atmosphere. Sometimes, during an east wind, the threads break faster than the piecers can join them; and it is not improbable that the rapid whirling of so many thousand pieces of machinery produces in very dry weather a large amount of electricity, which may prevent the proper spinning of the fibres. At such times it is not uncommon to keep the atmosphere of the room moist by jets of steam, and to maintain a temperature of from 68° to 76°. Indeed, fine yarn cannot well be spun at a lower temperature.

It will be seen by the above details, that considerable skill is required on the part of the spinner in the management of the mule. The demand for this kind of skilled labour has enabled the spinners to command high wages, and as prosperity requires a larger amount of self-knowledge and self-control than adversity, so the well-paid spinners, intoxicated by success, frequently committed the foolish acts of drunken men. As the quality of the yarn depended upon the care and attention of the spinner, it was thought impossible to execute by machinery that which required mind. This led the spinners on many occasions to league together for the purpose of compelling their masters to grant such wages as they chose to demand, and to accept such an amount of labour as they chose to give. Thus the mill-owners were subject to great disarrangement of business, and consequent loss, from the frequent "turn-outs" of the spinners, by which not only were their assistants thrown out of employ, but also the persons employed in the preparatory processes of carding, roving, &c., all of whom were, in the majority of cases, compelled reluctantly to cease from working, as the product of their labour was not required so long as the spinners remained idle. The spinners being provided with ample means, consequent on high wages, were able to continue the "strikes" for long periods of time. Their past successes led them to suppose that they alone were capable of directing and controlling the movements of the mule jenny, the value of which, if it had any in their eyes, depended upon the amount of skill which they themselves brought to bear upon it; they thought that they were necessary to the mule, not that the mule was necessary to them. They could not rise to the reflection that the amount of inventive thought, highly-trained mechanical skill, and well-applied science, which had been brought to bear upon this machine, from the moment when the apparently fortuitous circumstance of the upsetting of a domestic spinning-wheel suggested the invention to a man of genius, were still at work, the more unweariedly and the more incessantly as the spinners were the more refractory and the more troublesome to their employers. Many attempts had been made to produce a self-acting mule, but without success, until Mr. Roberts, of the celebrated firm of Sharp & Roberts, machine makers, succeeded completely in the invention of the self-acting mule, or the *iron-man*, as it is sometimes called in Lancashire. This extraordinary machine not only does the work of the spinning mule without the assistance or attendance of any one except the little piecer, but does it in a more perfect and complete manner, and produces a larger quantity of yarn. The cops, also, are firmer, and of better shape, and contain a larger quantity of yarn than cops of equal size wound by the spinner; and in weaving, the superior firmness of the cop allows the loom to be worked at greater speed, whereby cloth of a superior quality is produced in greater quantity. As mechanics become better educated, they will understand the principles which must regulate the demand and supply of labour: the employed have to consult the interest of the employer as much as their own, and unless there is a mutual interchange of good offices, both must suffer. "Strikes" and "turn-outs" have in many, if not most of the useful arts, led to the invention of highly ingenious machines, which have superseded labour, or, at least, skilled labour, so that the workmen who combine against their employers eventually injure themselves, and even annihilate their own occupation. It is not unusual for persons engaged in the Useful Arts to see the successful experiment of producing by machinery an important part of an article in most extensive use, which had hitherto been supplied entirely by hand, and to which self-acting machinery was thought inapplicable. The workmen, although (or because) in the receipt of good wages, had long been very troublesome to their employers. We regret exceedingly the thought that they will not have the opportunity of being so much longer.

REELING.—The yarn which is wound by the throstle upon bobbins, and by the mule is formed into cops, is, if intended for warps, wound off into measured lengths of 840 yards, called hanks. This is done by means of a six-sided reel, 1½ yard in circumference, mounted in a carriage which carries the spindles or skewers that bear the bobbins or cops; the carriage has a slow traverse motion, parallel to the axis of the reel, for properly distributing the thread upon its surface. The woman who attends to the machine, watches the revolutions, until a check is struck, which is done when the wheel has completed 80 turns, and as the circumference of the wheel is 1½ yard diameter, a *ley* or *rap* of 120 yards is thus formed; 7 of these raps make a hank of 840 yards. The hanks having been tied round with a string to separate and distinguish them, one of the arms which keep the reel distended is loosened, and the hanks are slid off by hand, and a fresh set is wound as before. The size of the yarn is ascertained by weighing the hanks in a balance called a quadrant. Tables are also published for readily ascertaining the number of hanks to the pound, but the following rule is practically correct:—Divide 1,000 grains by the number of grains in a ley, and the quotient will give the number of hanks to the pound. This rule is founded on the fact that a ley is 1-7th of a hank, and that 1,000 grains is equal to 1-7th of a pound. The usual average number of hanks to the pound is, for coarse spinning, from 10 to 40, but for some purposes, such as candle-wicks, coarse counterpanes, &c., such low numbers as 2 hanks to the pound are manufactured. Yarn of from 4 to 6 hanks is often exported. The highest number usually obtained in fine spinning is 300 to 400. Indian muslin is spun by hand so fine that 30 ells weigh less than 4 ounces; and some of the broad webs may be drawn through a moderately-sized ring. The work is said to be more like that of insects than of men, and almost justifies the Eastern term applied to it, of *woven wind*. Threads of this manufacture, when examined by the microscope, were found to surpass our machine-made muslin in

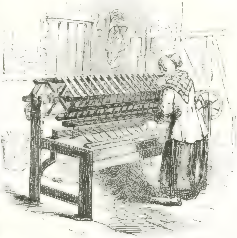


Fig. 667. REEL FOR WINDING AND COUNTING HANKS.

fineness, but to be inferior in regularity. Twenty yards of the yarn of this muslin weighed only 1 grain, and a pound of it would have reached the length of 115 miles. English yarn has been spun so fine that a pound would extend to 167 miles in length, but this could not be woven by our machinery. Dacca muslin has been sold in this country at 10 or 12 guineas per yard; but by the use of proper machinery and the division of labour, British manufacturers have produced muslin much cheaper than the Hindoos, and even of finer texture, but not so rich, or soft, or durable. Indian muslins are seldom seen in European markets, but they are still preferred in the East, where the merchants say they can distinguish the genuine productions of the Indian loom by the touch, and even by the smell.

Each size of yarn is sent into the market in cubical packages of 5 or 10 pounds weight. These packages are closely compressed, so as to diminish the bulk of the yarn, and preserve it from injury. The packages are made up in a simple but ingenious machine, called a bundling-press, Figs. 668, 669. It consists of a strong frame of cast-iron, situated beneath a wooden table BB, on one side of which is piled the yarn ready to be packed, and on the other the papers and twine used for making up the bundles. The bundles of yarn are seen in Fig. 668 between two upright sets of flat bars or rulers *b b*, Fig. 669, and resting upon a piece of wood upon the iron press-plate of the machine. In this wood are grooves for laying the packthread or twine, the loose ends of which are seen in Fig. 668 hanging down between the spaces of the five upright flat bars. The hanks having been slightly twisted and neatly folded together, and put into their places, as in the figure, the top rails *g g* are lowered, and the key-rods pushed into the slits of the rails. The man then turns the iron cross F, which acts upon a pinion C and a ratchet-wheel furnished with a click *a* to prevent the wheel from flying back: upon one of the radial arms of this wheel is a connecting-rod G, the upper end of which is joined by the press-plate, which must therefore move upwards when the wheel is turned round. The plate is furnished with two guide-bars, which move between flanges within the frames, and is thus carried up vertically. When the bundle is thus sufficiently compressed, the man binds the twine round it, then pushes the click out of the ratchet-tooth, and the elastic rebound of the cotton drives down the press-plate.

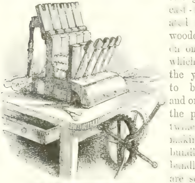


Fig. 668. BUNDLING PRESS.

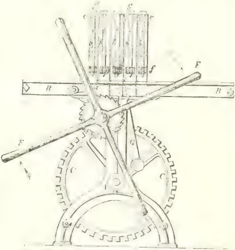


Fig. 669. WORKING PARTS OF BUNDLING PRESS.

GASSING.—Fine yarns are disfigured by a number of loose divergent fibres, which require to be removed in order to give them that level compact appearance which is required in the manufacture of bobbin-net-lace-thread, and for hosiery. The removal of these loose fibres without injury to the yarn would seem at first view a hopeless undertaking; but it is easily and successfully effected by one of those clever devices which so often excite our admiration in studying the processes of the useful arts. By passing the yarn rapidly through the flame of a gas-jet, the loose filaments are completely burnt off, the yarn is improved both in appearance and value, while it is diminished in weight, for a yarn of No. 90 thus becomes No. 95, making a difference of 5 hanks per pound by the operation of gassing.

The gassing-room is usually situated in the upper part of the mill, where the air is not likely to be disturbed. A large number of jets of coal-gas are burning on frames that occupy the length of the room: the jets are about 12 inches apart, and above each is a little hood or chimney. On entering the room, the smell of burnt cotton is perceived, and on approaching one of the frames, each flame is seen to be crossed in two or three directions by a delicate line apparently at rest; but on following the course of this thread, it is seen to proceed from one bobbin *d d*, Fig. 670, which is rapidly spinning round, and to pass through the flame to another bobbin or cone *b b*, which is also kept in rapid motion by being pressed against the tin drum *c* which is moved by means of the strap *a*. The intermediate thread is led over pulleys backwards and forwards through the flame, which thus singes off the loose fibres, converting them into a reddish kind of dust, which is very injurious, if inhaled. The rapid motion of the yarn through the flame prevents it from being consumed. On finally emerging from the flame, it is cleaned by passing over a brush. It then passes through a small hole or notch in a piece of brass, which is ingeniously arranged to detect any knot or foul point in the yarn. The hole is so small that there is but just room for the yarn to pass: if, therefore, a knot or other impediment occur in it, the piece of brass is depressed, and this is connected with mechanism which suddenly turns the gas-flame aside, and lifts the bobbin away from the rotating barrel. The yarn thus remains at rest, and the tenter-woman mends the defect, and sets the bobbin in motion again. Thus no time is lost, for while the defective thread stops, all the others are going on as usual.

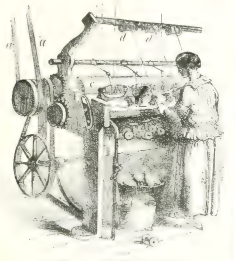


Fig. 670. "GASSING" THE THREAD.

DOUBLING AND TWISTING (*Manufacture of Thread*).—The word *thread* in non-technical language is usually applied to a thin narrow line of any fibrous material; but the manufacturer limits the term to that compound cord produced by doubling and twisting two or more single yarns. There are various kinds of thread, such as *bobbin-net-lace-thread*, *stocking-thread*, *sewing-thread*, &c. Lace-thread, which is made of fine numbers of yarn, usually from No. 140 to No. 350, consists of two yarns twisted together; sewing-thread usually consists of three or more single yarns twisted into one; stocking-thread varies in the number of its yarns according to the object of the manufacturer.

The doubling and twisting mill, or *thread-frame*, is a machine resembling in many points the throstle of the cotton-spinner already described. The doubling is effected by spindles and flyers, and the twist is usually given to the doubled yarns in an opposite direction to the twist of the individual yarns. The machine has one pair of rollers for the purpose of delivering the yarns at a measured rate to the twisting spindles, to ensure the proper degree of tension, and to promote an equable torsion. The thread, after being twisted, is wound upon bobbins mounted loosely on spindles, the bobbins being dragged round by the thread, as in the throstle-frame: the copping-rail on which the bobbins are placed has the usual up-and-down motion for ensuring the equable distribution of the thread over them.

Fig. 671 will further illustrate these arrangements. As the yarns are unwound from the bobbins or cops,

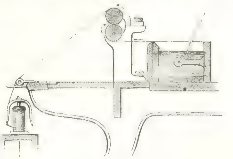


Fig. 671. SECTION OF THREAD-FRAME.

they are led across a glass rod, and passed into a leaden trough filled with water or a weak solution of starch; this wetting allowing the lines of yarn to twist into a more solid thread. On emerging from the trough, the yarns, 2, 3, 4, or 6 in number, according to the required size of the thread, are guided over a roller, which lays them parallel, or nearly so, and they are then passed down to the eyelet at the extremity of the flyer, the rapid revolutions of which twist them into a solid cord or thread, which is then wound upon the bobbin.

The thread is next made up into hanks for dyeing or bleaching, as may be required; and when dyed or bleached, it is wound upon bobbins for the purpose of *balling* or *reeling*. The process of forming the thread into balls or reels is performed with wonderful celerity in the following manner. A young woman is seated at a kind of turning-lathe, with the bobbin of thread mounted upon a spindle above her head: she seizes the end of the thread, and attaches it to a rod of steel, sets this spinning, and in an instant a ball of cotton appears at the end of the rod. The rotation is stopped, a blue ticket is inserted at the end, a further quantity of thread wound to secure the ticket, and the ball is finished. The size of the ball is regulated with great accuracy by the eye. The number of balls to the pound varies from 16 to 600; and the young woman being told to produce a certain number to the pound, makes a few, weighs them until she has got the exact size by weight; after this she relies entirely upon her eye, and so accurate is her judgment, that the variation of the balls in weight is very trifling. The cotton is also wound upon reels with surprising celerity; the steel finger which delivers the thread from the bobbin being guided to and fro to distribute it equally along the barrel of the reel. The quantity here also is judged of by eye, and varies from 30 to 300 yards in each reel. As each reel is filled, the broken end of the thread is inserted in a notch, which the winder cuts for the purpose. Reeling is not such rapid work as balling, but is still sufficiently swift to prevent the eye from following the motion of the thread. The chief delay in both cases arises from the breaking of the thread, which, during the writer's visit, occurred rather often.

The reels are placed on end in a kind of shallow drawer, and little children cut out and paste on the labels. These labels are printed on sheets, and the back of each sheet is covered with gum, like the postage stamps. The children stamp out the labels with a circular punch, wet the back of each against the tongue, and then press the wetted side against the end of the reel. Some idea may be formed of the extent of this business from the fact that a sheet containing 144 labels, printed in blue and gold, and glazed, and then covered on the back with a layer of gum, is sold for one penny. The smallest bronzed cotton bobbin-labels are sold as low as one halfpenny per gross.

The balls of cotton are tied up in small flat bundles, each containing a quarter of a pound; the proper number is counted out, folded up in paper, and tied into a bundle, with the remarkable speed and precision which is attained only by long practice: four of these quarters are next tied up into pound parcels, which, after being labelled, are ready for the wholesale market.

The amount of raw cotton imported into the United Kingdom during the three years named is as follows :—

		1859.	1860.	1861.
From United States	cwts.	8,586,672	9,963,404	7,316,959
,, Brazil	,,	109,705	104,347	154,478
,, Egypt	,,	436,613	392,447	365,108
,, British East Indies . .	,,	1,717,240	1,822,689	3,295,004
,, Other countries	,,	105,401	86,304	91,619
Total . .		10,946,331	12,419,096	11,223,678

In 1861 cotton manufactures were imported to the value of £783,043.

The computed real value of the raw cotton imported in the eleven months ending 30th November, 1861, is as follows :—From the United States, £26,549,717; from Brazil, £556,652; from Egypt, £1,279,840; from British East Indies, £7,278,537; from other countries, £275,309; making a total of £35,940,055.

Within the same period the value of the import of cotton manufactures not made up was £664,763.

The exports of raw cotton in 1861 amounted to 2,662,947 cwts., and of foreign cotton manufactures to the value of £139,878.

Our exports of cotton of British manufacture, including calicoes, cambrics, and muslins, fustians and mixed stuffs, were of the declared value as follows :—

1859.	1860.	1861.
£37,048,538	£40,346,842	£[illegible]

	1859.	1860.	1861.
Lace and Patent Net . . value	£397,[illegible]	£443,[illegible]	£[illegible]
Stockings	201,120	[illegible]	157,925
Counterpanes and small wares, except stockings	382,208	397,317	[illegible]
Thread for sewing	664,845	741,[illegible]	571,764
Cotton Yarn	9,458,112	9,870,875	9,292,841

The number of yards of calicoes, cambrics, &c., exported in 1861 amounted to 2,559,903,766. Thread for sewing in lbs. 5,129,348. Cotton yarn in lbs. 177,776,249.

Our best customers are the Hanse Towns, Turkey, America, China, and the East Indies; Holland takes the largest quantity of yarn.

COUPLINGS. When a line of shafting is of greater length than can be cast or forged in one continuous line, the ends of the shafts are joined together by what are called *couplings;* they are also used to disconnect parts of the gearing beyond a certain point of the line, and also to connect and disconnect particular machines.

It does not appear, at first view, to be difficult to unite or couple the ends of two shafts, so as to make them act as if they were one piece; nor would it be difficult if machinery could be made perfectly true, if their parts were not liable to wear and tear, and the supports not liable to settlement.

The most simple method of coupling, is to make the ends of the shafts square, and to use a square coupling box, whose interior dimensions shall correspond exactly to those of the ends of the shaft, so that when the ends are in their places in the box and one shaft is set in motion, the other revolves with it. If it be required to transmit motion along one shaft only, the box can be slipped back on one shaft, and the one which is disengaged can be removed either for the purposes of repair, or for giving rest to machinery, &c. which is driven by the shaft.

In coupling square ends, the motion will of course be smooth and continuous in proportion as the shafts are in a straight line, and the ends fit accurately. Accuracy in these respects is difficult to attain in large machinery, and if attained in the first instance, it would not continue long, on account of the wearing of the different parts, and the settlement of the supports. Hence the shaft in some part of its revolution is lifted off its bearings, thereby producing an unsteady motion, and much straining and wearing of the couplings, which in their turn suffer and increase the evil.

In small machinery which can be executed with care, and where the wear is comparatively small, the square coupling box can be used; but it is seldom employed in mill-work. An excellent coupling is a cylindrical box, in which two pins, at right angles to each other, are inserted through the box into the shafts to connect them together. This joint can be made with greater precision and at less expense than the square coupling, because the ends of the shafts and the box can be turned in the lathe, and thus be made to fit with great precision. There is no wear in this kind except in the holes and pins: the latter are easily replaced, but as they cannot be made to fit so accurately as at first, this form of coupling is not much used for heavy shafting.

Couplings are more easily applied when each shaft has two bearings; but it often happens that each shaft has but one bearing, in which case, a neat and compact mode of coupling, adapted to all kinds of shafting, large or small, is the *half-lap joint.* The ends of the shafts are made semi-cylindrical, and fitted together so that the tongue of one fits into the recess of the other, thus completing the cylindrical form; the joint is then covered with a thimble or ring, and is secured to it by a key. This coupling is accurate and durable, but expensive; it is much used in the better kind of millwright work.

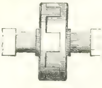


Fig. 672.

For shafts with two bearings, a method of coupling is shown in Fig. 672. The shafts are terminated with circular heads, one having teeth, and the other corresponding indentations to receive them. Should any slight settlement of the building, or other cause, depress one of the bearings or raise another, so as to throw the two shafts out of a straight line, these joints admit of a slight bending, and will, notwithstanding this, steadily communicate the motion of one shaft to the other.

A coupling first used by Mr. Murray of Leeds, for connecting a long line of shafts which carry a heavy strain, is shown in Figs. 673, 674. Should the shafts be out of line, this coupling acts as a sort of universal joint. A and B are the two shafts united; C D their necks or collars, which lie in the bearings; the ends projecting beyond these, have two boxes E F fixed on them by a square with wedges, or by a round part with a fillet; one box, E, has a piece projecting from the inside of it on each side, and extending into the other box as in *a a*, Fig. 673, which shows the inside of the coupling. The box F has two similar pieces projecting from it at *b b*, into the box E. Within the box, the iron cross *c c*, *d d* has screws fixed into the end of the arms by which motion is communicated. Now when the shaft A, and the box E are turned round in the direction of the arrows, the pieces *a a* act against the screws *c c* of the cross, and cause them to revolve, at the same time that the other two screws *d d*, at the other arms of the cross, press against the pieces *b b*, which belong to the box F, and the shaft B, thus causing them to rotate also. The cross is quite detached in the boxes, and thus acts as a universal joint to communicate the motion of one to the other; the screws *c c*, ***dd***, at the end of the cross, are only used in order that the acting points may be of smooth steel, and thus diminish friction. This method of coupling requires a bearing at each end of every shaft.

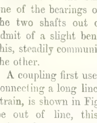


Fig. 673.

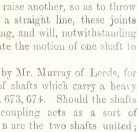


Fig. 674.

Mr. Murray also introduced another method of coupling, which requires only one bearing for every length of shaft. A, B, Fig. 675, are the two shafts, each with a pivot at the end; these pivots are fitted into the coupling box, C D E, bored inside to receive the ends of the shafts, and turned outside with a neck D D, working in the bearing. The shafts A, B, are connected with the coupling-piece D, at C and E, by means of a cross-key *l m* put through each shaft, the ends being received in notches inside the coupling-piece. The shafts do not fit tight in the pieces E and C, but only in the pivots *a b*, by which means, they have a little freedom of motion without straining the bearing in which D runs, because it is only the short coupling-piece which is received therein, so that a slight deviation from the straight line does not produce an injurious strain.

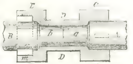


Fig. 675.

Dr. Hooke's universal joint, Fig. 676, is a method applicable to light machinery, of uniting shafts which are inclined to each other. The two shafts A and B, within the bearings C and D, terminate in a semicircle or fork; G is a circular iron ring within 4 pins or pivots *a a a*, on its circumference, which fit into holes in the ends of the forks, thus uniting them together, and allowing freedom of motion. In this way, a rotatory motion may be conveyed from the shaft to another when they have a considerable inclination, but if the angle formed by the two shafts be more than 15 degrees, it is advisable to use bevelled wheels, because when so much inclined, the universal joint works with great friction and irregularity of motion. These joints may be constructed with 4 pins, fastened at right angles upon the circumference of a hoop or a solid ball.

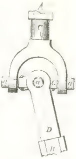


Fig. 676.

There is a form of coupling called *friction coupling*, in which the connexion depends simply on the contact of the surfaces. It is not applicable to heavy machinery, but in certain circumstances it is more advantageous than any other method, because by its means the machinery can be limited so as just to have sufficient friction to carry on the work with the ordinary resistance, but so little beyond it that should an accident happen or any thing get entangled with the machinery, the additional resistance will stop that part, while the other part continues to rotate, thus preventing damage to the work under operation, and injury to the workman. Fig. 677, is an example of friction coupling. One shaft, A, has a circular plate O cast on the end, fitting into a loose box on the end of the other shaft B; *b b* is a collar of leather, fitting within the enlarged end of the shaft B, so that when the nuts *a a* are screwed up, it causes the box to press against the collar of leather, and by its friction puts the shaft in motion. The collar of

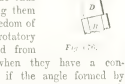


Fig. 677.

feather is sometimes placed at the end of the shaft, as at *e*.

For various methods of engaging and disengaging machinery, see GEARING.

COURT PLASTER. A black sticking-plaster, made by taking ℥ss of benzoin and ℥vj of rectified spirit, dissolving and straining them; then taking ℥j of isinglass and Oss of hot water, and dissolving and straining them separately from the former. The two are then mixed and set aside to cool, when a jelly is formed, which is to be warmed and brushed ten or twelve times over a piece of black silk, stretched smoothly. When this is dry, a finish is given by a solution of ℥iv of Chian turpentine in ℥vj of tincture of benzoin. Court plaster is made more adhesive by the addition of caoutchouc.

CRANBERRIES. The fruit of a species of *vaccinium*, a family which produces the Whortleberry and the Bilberry. Cranberries are very abundant in North America, and in the northern parts of Russia. They are also found in mossy bogs in different parts of Scotland. The Russian cranberries are esteemed the best. The fruit is red and about the size of a currant, growing on a diminutive plant, in boggy situations. It makes an agreeable preserve. Our importation of cranberries amounts to thirty or thirty-five thousand gallons annually.

CRANE. A machine for lifting heavy weights. Until within a period comparatively recent, the construction of cranes was of a very rude and inartificial character; but the necessity which has arisen, as a consequence of the advance of arts and manufactures, for lifting and transporting with ease and rapidity ponderous machinery, stones, timber, and vast bales of goods, has led to the construction of instruments far more efficient in their operation, and at the same time more skilfully and artificially arranged.

The more important parts of a crane are known by the names following:—The *crane-post* or *stalk* (B C Fig. 680) is the upright post of wood or iron, on which the crane turns. The *jib* is the horizontal or inclined beam, from the end of which the weight hangs (A C Fig. 680). The *stay* is the piece which supports the jib from underneath (Figs. 679 and 680), this in iron cranes is usually replaced by *tension-bars*, (A B, Fig. 680), of wrought-iron, placed above the jib. The *barrel* is the drum or roller around which the chain is coiled.

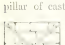


Fig. 678.

Cranes for landing-wharfs and quays are now usually made of iron. The crane-post is a hollow pillar of cast-iron, stepped at its foot into a cross-shaped framing of cast-iron, and passing through a similar framing at the level of the ground. The extremities of the crosses, Fig. 678, are bolted together through a mass of masonry, so as to render it impossible for the crane to move or overset. The jib may be of cast-iron, in the form of a simple pillar, cross-shaped in section, or if the crane has to carry a heavy weight, it may assume the form of a deep framing, or of two such framings bolted together side by side. The jib is frequently made of a pillar of wood, supported at its ends in strong sockets of cast-iron. The tension-bars of wrought-iron at the top, form eyes to encircle the pivot of the sheave, or are keyed or pinned to the upper socket of the jib. At the bottom they are keyed or bolted to a framing of cast-iron, which carries the wheel-work, and which turns on a pin at the top of the crane-post. The lower part of this framing turns on a collar at the foot of the crane-post. The foot of the jib is connected to this collar, either resting entirely upon it or upon a wheel running on a rail of iron let into the masonry. The latter plan, as it throws less strain on the crane-post, is generally used with heavy cranes.

The wheel-work depends for its strength and the number of its wheels on the weights to be raised. It has been found that an ordinary labourer cannot work well for any length of time against a pressure of more than 15 lbs. at the level of his chest; so that whatever be the weight to be raised, the average stress on the winch-handle must be reduced, by the wheels and pinions, to this pressure for each labourer intended to work at the handles. The winch-handles are about 18 inches in radius, and a good height for their centres from the ground is 3 feet or 3 feet 2 inches.

A brief examination of the mode of application to a simple case of the principles which regulate the construction of cranes, will enable our readers to apply those principles to other and more complex instances.

Fig. 679 is a sketch of a 1½-ton wharf crane, constructed by Messrs. Lloyd, Foster & Co. of Wednesbury. Fig. 678, is a plan of its foundation, and

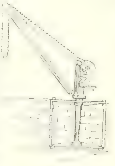


Fig. 679.

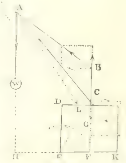


Fig 680.

Fig. 680, a diagram of its principal parts, to show the distribution and resolution of the strains.

Beginning with the chain or rope, we find that the strength of chains of medium substance varies as the square of the diameter of the bars from which they are made. A chain with plain short links made of one-inch iron, should bear a weight of 32 tons, and a similar chain with studded links, nearly 40 tons. A rope of 3 inches circumference will bear about 2 tons, and the strength of ropes increases as the squares of their circumference. But neither ropes nor chains should be worked with more than one half of the weights thus given.

The total strain produced by the load and its suspending chain and blocks, (if such be used,) upon the end of the jib, may be resolved by the parallelogram of pressures (See CARPENTRY) into two forces, one straining the tension bars, and the other compressing the jib. If this be done as in Fig. 680, the force on the jib will be found to be about $4\frac{3}{4}$ tons, and the strain on the tension-bars about $3\frac{3}{4}$ tons, with a suspended weight w of $1\frac{1}{2}$ tons.

The strength of the tension-bars varies directly as their sectional area. A bar of good English iron one square inch in section, will break with about 20 to 25 tons of longitudinal strain. But as it is permanently elongated with half this weight, it must never in practice be exposed to more than $\frac{2}{5}$ths of it, say 10 tons per square inch of section.

The jib may be regarded as a pillar exposed to compression in the direction of its length. The strength of such a pillar was found by Mr. Hodgkinson to vary[1] nearly directly as the fourth power of its diameter, and inversely as the square of its length. The following rule has been given for finding the diameter of the column to bear a certain pressure:—

"Multiply the square of the length, in feet, by the load to be borne, in pounds. Divide by 10 times the modulus of elasticity given in Mr. Barlow's tables for the material of the column, reducing this modulus to its value for feet by dividing by 12^3 or 1728. The quotient is the fourth power of the side of a square pillar which will bear the pressure. If the pillar is to be round, multiply the quotient by 1.7, and then extract the fourth root. The result is the diameter of a round pillar."[2] Thus, in the case of Fig. 680, if the jib had been a round pillar of Riga fir, the modulus of elasticity of a mean specimen of which is, in Mr. Barlow's tables, 145,000, we have, since $4\frac{3}{4}$ tons $= 10,640$ pounds, and the jib is about $14\frac{1}{4}$ feet long:—

$$\frac{14.25^2 \times 10640}{\frac{145000}{1728} \times 10} = \frac{203.06 \times 10640}{839} = 294.$$

Therefore, if the jib were to be square, its side must be $\sqrt[4]{294} = 4\frac{1}{4}$ inches nearly.

If the jib were to be round, its diameter would be $\sqrt[4]{1.7 \times 294} = 4\frac{3}{4}$ inches.

The ends may have their diameters lessened by from 1-6th to 1-7th, so as to give the jib somewhat of a spindle shape, without diminishing its strength. The ends should not be rounded, but should be cut quite square, and be made to abut very evenly on the bottoms of the cast-iron sockets into which they fit. Experiments have shown that by rounding the ends of a pillar its strength is diminished to one-third of what it would be with the ends flat.

The values of the modulus of elasticity found by Mr. Barlow's experiments, are to be regarded as applicable only to really fine specimens of the various materials. Due allowance must in practice be made for middling or faulty specimens.[3]

The strain of the tension-bars and the thrust of the jib evidently tend to break the crane-post across just above the ground. Each of these oblique forces may be resolved (as in Fig. 680) into two others, one horizontal, and tending directly to break the post across, the other vertical, and having no tendency to produce fracture. The crane-post may be regarded as a hollow beam, supported at its two ends B and F, and bearing at an intermediate point C a weight equal to the sum of the resolved horizontal forces. These in our figure amount to about 3 tons and $2\frac{3}{4}$ tons.

The resistance to rupture of a solid cylinder supported at both ends and loaded in the middle, is determined by the equation, $W = \frac{\pi S c^3}{a}$; where $W =$ breaking-weight, $\pi = 3.1416$, $S =$ modulus of rupture of the given material, to be taken from Barlow's or other book on the strength of materials, c is the radius, and a the length of the cylinder, all dimensions being taken in inches. Also the strength of a hollow cylinder bears the same ratio to that of a solid cylinder of the same material, as the difference between the fourth powers of the outer and the inner diameters, divided by the outer diameter of the hollow cylinder, bears to the cube of the diameter of the solid cylinder.[4] The weight which any beam will bear when placed at its middle, is to the weight which it will bear at any other point, as the square of half the length of the beam is to the product of the distances of the point of suspension from the ends of the beam. These results give the breaking-weights. The working-weights in practice should never exceed one-half of these amounts.

Figs. 679 and 680 show the manner in which the foot of the crane is embedded, as it were, in a solid block of masonry. It is evident that on the sufficiency of this block to resist the tendency to overturn, produced by the weight of the jib and its suspended load, depends the whole stability of the structure. To ascertain the sufficiency of the block for this purpose:—Since the whole system tends to overturn on the angle E, we measure from this angle the moments of the two opposing weights, which are here, the block of masonry with the body of the crane, and the projecting jib with its load W. Therefore we have, by the equality of moments,[5] calling G the

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[1] The formula for the breaking weight of a cast-iron solid column is $W = 44.16 \frac{D^{3.55}}{L^{1.7}}$; where D is the diameter, in inches, and L the length, in feet; W being the weight in tons. This is for columns whose lengths exceed 25 times their diameter.

[2] Glynn's Treatise on Cranes, published in Weale's Rudimentary Series.

[3] The following are values of the modulus of elasticity for some materials ordinarily used for crane jibs:—

Red pine	[illegible]	Barlow.
Riga fir, mean	145,000	,,
Norway pine	[illegible]	,,
Oak, English	[illegible]	,,
,, Canadian........................	[illegible]	,,
Cast iron, highest value	[illegible],770,	Fairbairn
,, lowest value	[illegible]	,,

[4] See Moseley's "Mechanical Principles of Engineering," p. [illegible]

[5] The principle of the equality of moments will be explained in the article MECHANICS. See also Tomlinson's "Treatise on Mechanics," published in Weale's Rudimentary Series.

weight of the block of masonry, C the weight of the crane, and ω the weight of the jib:—

$$(C + G) \times EF = (W + \omega) \times EH;$$
$$\therefore\ C + G = \frac{(W + \omega) \times EH}{EF}.$$

Whence, C being known, the required weight of G necessary to prevent overturning with a given weight W, may be found. The actual weight of the block should in practice be three or four times as great as the result thus deduced.

It is evident that if the jib, instead of resting against the crane-post, bore against a circular rail let into the masonry, as shown by the dotted jib in Fig. 680, less strain would be thrown on the crane-post. This is commonly done in cranes intended to lift very heavy weights.

The journals or bearings of the axles should be from $1\frac{1}{2}$ to 2 times their diameters in length, to avoid cutting. Their diameters must be determined by their required power to resist the torsion of the wheels. The resistance to torsion varies directly as the cube of the diameter, and inversely as the length of the rod strained. It is stated that a force of 120 lbs. acting on a winch-handle of 18 inches radius, does not practically twist an axle 2 feet long and $1\frac{1}{2}$ inch in diameter.

The journal of the crane-barrel has to bear the transverse strain of the weight. The rule given for determining the strength of axles so strained, is to make them proportional to the cube root of the stress to be borne in hundredweights, if of cast-iron, or proportional to the cube root of $\frac{9}{14}$ths of this stress if of wrought-iron. Thus, if a journal has to bear $1\frac{1}{2}$ ton or 30 cwt., its diameter should be $\sqrt[3]{30} = 3\frac{1}{10}$ inches, if of cast-iron, or $\sqrt[3]{\frac{9}{14} \times 30} = 2\frac{3}{4}$ inches, if of wrought-iron.

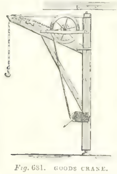

Fig. 681. GOODS CRANE.

Fig. 681 shows a form of crane used for unloading light goods and packages. The power is communicated from the winch-drum by a rope, which, as it uncoils from the wheel above, winds up the chain on the barrel.

Fig. 682 is a sketch of a form of steam crane used at the Camden Town Railway Station. A steam-engine keeps the shafting at the top with its several driving-wheels in motion. When the man pulls the check-rope, he lifts the crane-barrel about one axle, and raises the wheel of the barrel up, to press against the driving wheel above. The friction between the two wheels, increased as it is at pleasure by the man below, suffices to turn the crane-barrel and lift the weight. If the rope be slackened so as to lower the crane-barrel a little, it clears the driving-wheel, and yet does not drop into its bed, where it would rest immovable. In this position the weight descends freely, or the chain can be uncoiled. The driving-wheel is not vertically over the crane-wheel, so that the two coming obliquely into contact, are pressed together with more force.

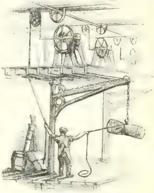

Fig. 682. STEAM CRANE.

Fig. 683 is a sketch of the traversing-crane now much used in large buildings, timber, and stone-yards. The whole framing traverses longitudinally on rails by means of a winch and toothed wheels. If both windlasses are turned at once, it is evident the weight will be raised. If one be unwound with the same speed that the other winds the chain, the weight will neither rise nor fall, but simply traverses towards the winding side. The action of this crane is sufficiently explicit without any detailed description.

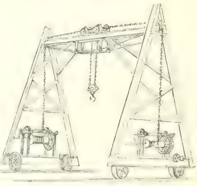

Fig. 683. TRAVERSING CRANE.

At Newcastle-on-Tyne, Glasgow, Liverpool, and some other places, the pressure of a head of water acting upon a moveable piston has been employed to lift weights, by means of a crane arranged somewhat as shown in the sketch, Fig. 684. E is the pipe which supplies the water to the crane, A the cylinder and piston for lifting the weight, and B a smaller cylinder for turning the crane round by means of the rack and wheel. The admission of the water to this last cylinder is regulated by the valve C, and to the large lifting cylinder by the valve D. The waste-pipes and cistern, safety-valves, and relief-valves, are not shown in the sketch. The piston of the lifting-cylinder is connected to a single pulley moving on a bed rail, part of which only is shown in the sketch. The chain passes over this pulley and two other fixed pulleys before passing up the hollow crane-post, so that the extent of motion of the piston in A is magnified three times in acting upon the chain. The weight may therefore be lifted through a higher space, but of course with proportionately less force. A detailed description of this crane is given in Mr. Glynn's Rudimentary Treatise on Cranes.

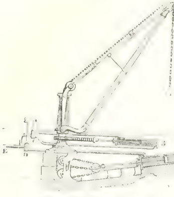

Fig. 684.—WATER CRANE

It has been proposed to apply the force of a vacuum, maintained constantly by a pumping steam-engine, as the motive power of cranes. Its application would of course nearly resemble that of the water, though it would be less manageable, and also far more limited in its power, as the pressure on the piston could never exceed that of the atmosphere, or about 15 lbs. per square inch.

Fig. 685, is a drawing of a double crane, which was employed in the construction of the pier and breakwater at Aberdeen. The whole framework of the crane travels on a temporary railway, so that it can be advanced to or drawn back from its work. By having two jibs, the work of unloading and placing the stones can be proceeded with very rapidly. The nippers used in holding the stones are peculiarly applicable to sub-aqueous works. The moment the stone rests on its own bed, the chain slackens, and the nippers release their hold. Were the stones suspended by a *lewis*, a diver must be constantly employed in deep water to release the stone when placed.

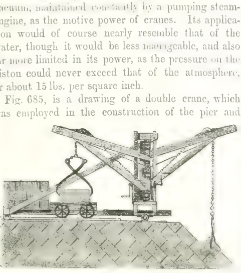

Fig. 685.

It has been suggested that steam may be used in the same manner as the water in Fig. 684, the lift of the crane being completed by one stroke of the steam-piston attached to the crane, and not, as usual in steam-cranes, by the temporarily-applied power of a small steam-engine.

A very efficient form of crane has been constructed by Mr. Neilson of Glasgow. The framing and wheel-work is the same as in the common wharf crane, but the motive-power is supplied by a small steam cylinder and piston attached to the framework, and acting upon the wheels by a connecting-rod and crank, as in the steam-engine. The steam-pipe passes up the crane-post, and is connected with the cylinder by a stuffing box joint, which allows of the free rotation of the crane about its post. The boiler may be fixed in any adjoining warehouse or shed. A drawing of this crane will be found in the Practical Mechanics Journal, Part 36, March, 1851. [See Appendix.]

CRANK, see Steam Engine.

CRAPE, a transparent fabric made of raw silk with the gloss removed, and dyed usually black. The weaving is very simple, and the dressing is finished with a stiffening of gum-water. See Silk.

CRAYON, see Blacklead—also Appendix.

CREAM, see Butter.

CREOSOTE, see Kreasote.

CRUCIBLES, open vessels for the reception of bodies which are to be subjected to high temperatures. The Alchemists made great use of these vessels, and were accustomed to impress the sign of the cross upon them; hence the name, from *crux, crucis,* a cross. Crucibles are of various forms and materials, according to the uses to which they are applied. They are mostly of earthernware, on account of the economy of this material, and its power of resisting a high temperature. The cheapest are the common *English crucibles*, made of a triangular or circular form, with covers of the same material. They bear a bright red heat; but at a very high temperature they soften and froth, and, under the action of a flux, fuse very readily. *Hessian crucibles* are very superior to the English in resisting high temperatures and the action of fluxes, nor do they become vesicular when powerfully heated. They are triangular in shape, and are not usually furnished with covers. *Cornish crucibles* are made in Cornwall of different sizes, and round in shape, for the use of the assay-masters there. They possess the good properties of the Hessian. *Wedgwood's crucibles* are made of a close white ware; they are round, well formed and finished, and their covers fit well. They are liable to crack by being heated or cooled. *Blue pots* or *black-lead crucibles* are made of a mixture of coarse plumbago and clay, and usually of large size. They bear a higher temperature than the English crucible, and are not so liable to crack. They also resist the action of fluxes at moderate temperatures. They contain a good deal of iron and charcoal. Melting-pots formed of Stourbridge clay and pulverized coke bear very high temperatures, and with care are not liable to crack in the fire. Crucibles are also formed of platina, pure silver and iron. The management of crucible operations, fusion and reduction, are described in Dr. Faraday's work on Chemical Manipulation, Section XIII.

CRYSTALLIZATION is that exertion of the force of cohesion among the particles of a solid, by which it is withdrawn from its solution in a liquid. In a great variety of cases the particles do not solidify into confused masses, as might be supposed, but arrange themselves with the utmost order into certain geometrical forms called *crystals.* Thus if a portion of the water of a solution of sugar be driven off by slow evaporation, and the concentrated syrup be left for some time at rest, a regular solidification takes place; the force of cohesion builds up the solid into the symmetrical well-known forms of sugar-candy. But if the process be hastened or disturbed, we get loaf-sugar, in the formation of which crystallization commences at myriads of points at the same instant, and neither time nor space is allowed for the particles to expand to a large size and regular outline.

That very important and extensive class of bodies known as salts, crystallize from their solutions into forms of the utmost symmetry and beauty; and these forms, as also those of *native* minerals, or those met with in nature, are characteristic of particular salts or minerals; for each salt or mineral may be said to have as much a distinct shape of its own as each plant or animal, and may be as readily distinguished by the characters presented to the eye. Thus common salt assumes the form of the cube; alum, that of a octohedron; saltpetre, that of a six-sided prism; epsom salts, that of a four-sided prism.[1] The largeness and regularity of the forms of crystals is generally proportional to the slowness of the operation, and the quantity of the solution from which the crystals are deposited. Many of the crystals which have been formed by the hand of nature have hitherto resisted the efforts of science. Thus rock-crystal is found in beautiful six-sided prisms, the diamond in octohedrons, &c., but these were most probably produced by the operation of forces similar to those which can be watched and studied in our laboratories.

The operation of the force of cohesion, which binds the particles of crystals together, is determined by apparently very slight causes. Thus the agitation of a saline solution, or the contact of some foreign substance, or especially of a crystal of the same substance, will cause crystallization to commence. It will nearly always take place around any solid centre or nucleus that can be wetted by the liquid. In the manufacture of sugar-candy, verdigris, sulphate of copper, prussiate of potash, &c. strings, twigs of wood, and wires are placed in the solutions, and may generally be found in the centres of large groups of crystals. The use of the nucleus seems to be this:—A portion of the water of the solution attaches itself to the solid, which it wets, and is thus withdrawn from the solution, the crystallization of which is thus determined. An instructive example of this is seen in the common alum basket. A delicate frame-work of a basket or some other object is placed in a solution of alum or of sugar. After a time it becomes a basket of finished gems, the crystals glistening with their many polished facets. In the manufacture of tarraric and citric acids, the rough brown crystals of the first process are always much larger and bolder than those of the pure transparent products of the last operation. This arises from the presence in the first solutions of earthy or carbonaceous matter in a minutely divided state, which act as nuclei. If the nucleus be a salt of the same kind as the salt to be crystallized, it will act in a remarkable manner in a mixed solution of two salts, such as 2 parts nitre and 3 of glauber salt (sulphate of soda) dissolved in 5 of warm water. If two bottles be filled with the solution, and we put into one a crystal of nitre, and into the other a crystal of sulphate of soda, and place both in ice-cold water, nitre only will crystallize in the one, and sulphate of soda in the other. This property of one salt crystallizing in preference to another contained in the same solution, is of frequent use in purifying and separating crystalline substances. An ingenious process, introduced a few years ago for separating silver from lead, depends upon the property of the silver forming crystals in the fused lead before crystals of lead begin to appear. [See **LEAD.**]

The effect of vibration in determining or modifying crystallization is exhibited in certain cases at temperatures far below those required for fusion or solution, which is most commonly necessary as a preliminary step to crystallization. When iron is subjected to long-continued vibration, especially under pressure, its tough fibrous character becomes changed into a coarse crystalline one; that is, certain of the fine crystalline grains become enlarged at the expense of others, and thus the cohesive force of the mass is diminished. Many accidents in machinery arise from this cause. It has also led to the fracture of the axles of railway and other carriages, and of grindstones, &c. Even the iron rails of a railroad may thus become weak and useless.

Very large and perfect crystals may be formed by repeatedly transferring a crystal from one saline solution to another of the same salt a little more concentrated, evaporating at very moderate temperatures, or even spontaneously at common temperatures. The most perfect crystals of gems are met with in nature of only moderate size. The larger ones are less clear, and even opaque, and the faces lose their smoothness, and much of their lustre. The emerald sufficiently pure for jewellery does not often exceed an inch in length, and is seldom so much as this. Clear garnets fit for setting are seldom half an inch through. Transparent sapphires above an inch in length are very rare. Quartz crystals sometimes attain a very large size. There is a quartz crystal at Milan which measures $3\frac{1}{4}$ feet in length, and $5\frac{1}{2}$ in circumference: its weight is 870 lbs.

The crystalline arrangement of an amorphous block may be developed in a pleasing manner by a contrivance first pointed out by Professor Daniell. If we take a large lump of alum, and remove from it all traces of external crystalline form by cutting and grinding, and place this in a vessel of water, the fluid will at first act upon it in all directions alike; but as the water becomes saturated with the alum, the salt gives way only or chiefly along the lines of least resistance, which are determined by the regular structure of crystalline arrangement. Under these circumstances, the surface becomes embossed with the forms of octohedrons and sections of octohedrons. Other salts present analogous phenomena, and metals which have been slowly cooled from a state of fusion exhibit a similar regular arrangement of their particles when thus dissected by the action of acids. A mass of nickel thus treated, soon becomes covered with tetrahedral figures of great relief and beauty by the action of nitric acid; so also does gold carefully cast and cooled, by the action of aqua regia. The beautiful forms of the *Moirée métallique*, which formerly excited so much admiration in their application to ornamental purposes, were produced by the action of weak acids on common tin-plate, the different colours being given by means of transparent varnishes. The cheapness of the operation soon brought it into disrepute. By the action also of dilute muriatic acid, pure malleable bar iron may be dissected into bundles of fibres, running in a parallel and unbroken course throughout its length; while different varieties of cast-iron will by the same means present congeries of plates, and a structure more nearly approaching the crystalline. By the action of quicksilver upon a small bar of tin, the crystalline structure was beautifully shown: the bar was placed horizontally in the mercury, and frequently turned upon its different faces, so as to ensure uniformity of action; in about 24 hours, fissures appeared along its lateral and terminal edges, which, by gradually splitting, resolved the bar in four equal three-sided rectangular prisms, which, as well as two pyramids for their extremities, could be separated from each other by the point of a knife. A similar effect may be produced by careful hammering upon bars of malleable metals. If square bars be hammered upon the edges, and the blows repeated round them so as to give them a cylindrical shape, they soon become *rotten* and break into fibres: but when the blows are directed parallel to their faces, they are capable of great extension; but many of them by alternate hammering upon each face, ultimately split along the edges in a manner very similar to that which is produced by the action of the mercury on the bar of tin. When it is desired to give a round form to any part of a square bar, it is confined in a form or mould, and the mechanical force thus applied produces an equality of pressure. It is by a similar equalization of the pressure, that some metals admit of being drawn into fine wires through circular holes in steel plates.

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[1] [illegible] than the apparently endless variety of figures in the ice which forms upon our window panes by the cold on the outside condensing the moisture of our breath, &c. within; the hoar frost upon trees, bricks, and grasses, and the wondrous variety of flakes of snow. All these figures are limited by certain laws, and the lines which bound them form among themselves no angles, but those of 30°, 60°, and 120°. If we let the end of a walking stick fall upon the ice of a small pond or puddle after a night's frost, the fracture will generally present a star with six equidistant radii or angles of 60°.

Some crystalline solids slowly change their internal structure, as already noticed in the case of fibrous iron changing into crystalline. For example, sugar which has been rapidly boiled down to a solid consistence, as in *barley-sugar*, is transparent, is broken with difficulty, and has a glassy fracture. After a short time, it becomes opaque and almost friable. Brass wire, as already noticed [BRASS], becomes in the course of time brittle and unfit for mechanical applications. If crystals of sulphate of nickel or seleniate of zinc, in the form of prisms, be laid on paper and exposed to the sun, they become in a few moments opaque, and when broken up, are found to consist of minute octohedrons with square bases. Fresh sublimed iodide of mercury is of a sulphur yellow colour, but if scratched with a hard substance, such as the point of a pin, some readjustment of the cohesive force takes place, and the colour changes to a bright red. Some kinds of sandstone which have been used as the hearths of furnaces, from long exposure to a moderate heat acquire a crystalline texture. Many vitreous compounds, such as the slags of furnaces, form into globular masses of radiating and acicular crystals. Arsenious acid, recently fused or sublimed, is usually glassy and transparent, but it gradually becomes opaque, white, and crystalline, the change commencing at the surface, and proceeding slowly to the centre. [See ARSENIC.]

Light has a powerful action in influencing this cohesive attraction, and determining the crystallization of certain substances. Thus in the druggists' shops, the camphor contained in the glass jars in the window is arranged in beautiful crystals on the side of the jar nearest to the light. In a glass vessel containing a saline solution, capillary crystals shoot up and attach themselves only to that side of the vessel which is most strongly illuminated. By placing a screen before the vessel, the line between light and darkness will be found distinctly marked by the limit of crystallization. Solutions of metallic salts exhibit this result most effectually.

Such are a few facts connected with the important and beautiful science of Crystallography. The reader who desires to study this must consult treatises especially devoted to the subject. A knowledge of the determinate forms of crystals is very useful in enabling the mineralogist to distinguish one mineral from another, and the chemist to distinguish between the different classes of salts. The manufacturer also avails himself of crystallization to cleanse, purify, and prepare a number of substances useful in the arts, the purity of which is often judged of by their crystalline forms.

CUBE, a regular parallelopiped, whose ends are squares, and whose height is equal to the side of its end. A box of equal length, breadth, and depth is a cube. Being the simplest of all solids, the cube is taken as the measuring unit of solid content, as the square is that of superficial content or area. Whatever the unit of length may be, the unit of solidity is the cube, which is a unit every way, such as a cubic inch, a cubic foot, &c. A cubic or solid foot contains 1728 cubic inches; for as the area of the base contains 144 square inches, and as the cubic foot is 12 inches in height, it would allow 12 layers of cubical inches to be piled up to complete the figure, or 144 cubes × 12 = 1728: hence, to find the solid content of a cube, we must multiply the area of its base by its height.

CUDBEAR, See Archil.

CUPEL, See Assaying—Bone.

CURRYING, See Leather.

CUTLERY. The cutting instruments of rude nations are shells, flints, and sharp-edged stones. The stone *celts* found in the barrows of our island are the knives of the ancient Britons. The use of iron and steel was known at an early period; but brazen instruments being more easily fabricated, were more frequently in use. There is no record of the time when cutlery was introduced into Great Britain. It appears from the Custom-house books, that long before the time of Henry VIII. we had an import trade in knives. In the fifth year of Elizabeth, this import trade was restricted, with a view to encourage the home manufacture. At that time, London was the chief mart for the finer articles of cutlery, but Salisbury, Woodstock, Godalming, and Sheffield, also carried on a considerable trade. According to Stow, "Richard Matthews, on Fleet Bridge, was the first Englishman who attained the perfection of making fine knives and knive-hafts;" and he states that at the time of the prohibition above referred to, "and for many hundred years before, there were made in divers parts of this kingdom many coarse and uncomely knives." In 1417, the London cutlers obtained a charter of incorporation from Henry V., and their hall in Cloak Lane is still maintained. Long before this, Sheffield had become celebrated for its knives: thus, Chaucer speaking of the whittler of Trompington, says:—

> "A Shefeld thwytel bare he in his hose,"

this instrument being a case-knife or whittle, used for cutting food, &c. The cutlers within *Hallamshire*, as the district about Sheffield is called, were not incorporated until 1624, but special rules for the government of the craft were formed at a much earlier period. The incorporation was founded on an act "for the good order and government of the makers of knives, sickles, shears, scissors, and other cutlery wares in Hallamshire and parts near adjoining." It is required by this act that, "all persons engaged in the said business to make the edge of all steel instruments, manufactured by them, of steel and steel only; and to strike on their wares such mark, and such only, as should be assigned to them by the officers of the company." These corporation marks are of great value as affording a guarantee of the superiority of the wares upon which they are stamped: they are protected by law, and it is illegal to forge or imitate them. Some of the most important houses still preserve their name and corporation mark, and refuse to put any other on their wares; but it is a very common practice for manufacturers to stamp on their goods the name of the retail dealer instead of their own: and in some cases, common iron knives are stamped with the words "shear steel," &c. Such dishonesty is very reprehensible, and tends to injure our character as a manufacturing nation.

Beckmann, in his "History of Inventions," has an amusing chapter on "Forks," which appear to be of comparatively recent use at table: they are still unknown in the East, where the meat is cooked so as to be exceedingly tender, and it is pulled to pieces with the fingers. Forks appear to have been first used at table by the Italians, towards the end of the fifteenth century.

The various causes which tend to concentrate a manufacture in a particular town or district, have long been in operation at Sheffield. The reputation of this town for the manufacture of knives and forks and various articles of cutlery is still maintained, and there is scarcely a more acceptable present on the continent than a Sheffield penknife or a pair of scissors. It is, however, greatly to be feared that the frequent disputes between masters and men on the subject of wages have injured the cutlery trade by causing doubt and uncertainty in the market. For example, various articles of cutlery are sold from patterns stitched on cards with the prices annexed; and as these prices are adjusted with great nicety to a scale of small profit on quick returns, it may happen that before a set of pattern cards with new prices attached can reach America, or have begun to circulate there, some alteration takes place at home, and other cards and corrections must be sent out, so that the foreign dealer throws discredit on the British manufacturer, who is often left to the mercy of workmen who cannot or will not see that their own interests are intimately bound up with those of the master manufacturer, who on his part has to provide capital, to stem the tide of competition, and to consult the interests of his customers at home and abroad.

The great variety of cutting instruments, and articles which come under the denomination of cutlery, are or ought to be manufactured wholly of steel, at least as far as the working parts of each instrument are concerned. Unfortunately, the great demand for cheap articles has led to the use of pig-iron in the production of knives, forks, razors, &c. An iron knife may have its uses, however inferior to steel, but an iron razor is of no use for the purpose to which razors are specially applied. At all good houses, either common steel or shear or cast-steel is used. Shear steel is very plastic and tough, and is used principally for edge tools which require great tenacity without much hardness, as in table knives, scythes, plane-irons, &c. Articles requiring a very fine polish, as razors, scissors, penknives, &c., ought to be of cast-steel; but as cast-steel can be welded to iron with great ease, the cutting part of chisels, plane-irons, &c. is made of the superior, and the rest of the tool of the inferior metal.

The forging of small works, such as articles of cutlery, differs in many respects from the forging of large works, which will be noticed under the article Forging. In forging small works, two men are usually required, and the work is then said to be *two-handed*. The principal man, named the *fireman*, manages the work both in the fire and on the anvil; he is furnished with a small hammer of from 2 to 4 lbs. weight, with which he directs his mate, who is named the *hammer-man*, from the circumstance of his having to wield a sledge-hammer of from 10 to 14 lbs. weight or more: it is his duty also to blow the bellows. The hearth is raised about 2½ feet from the ground: it is built hollow with an arch beneath for the ash-pit. A single hearth is about a yard square, and a hearth which has two fires under the same hood is about 2 yards by 1 yard. The hearth is furnished with a double trough for containing water in one compartment and coals in the other. The ordinary double bellows is used. The anvil weighs from 2 to 4 cwt., and is raised about 2½ feet from the ground.

Small works are usually forged at once from the end of a bar which is called the *porter*, after it has been cut off to be finished, or when the bar is too short to be held by the hand, tongs are used, of which there are various forms. Fig. 686, represents a pair of *flat-bit* tongs: they fit closer for thin works;

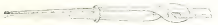

Fig. 686.

the jaws are always parallel, and a ring or coupler is put on the handles or *reins*, as they are called, to maintain the grip of the work. Others are made with hollow half round bits, to retain firmly round or square bars; or they are swelled open behind in order to hold bolts and other objects. Fig. 687, is a common form of tongs used by the Sheffield cutlers: they are called *crook-bit* tongs: the jaws overhang the side so as to

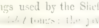

Fig. 687

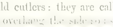

Fig. 688

allow the bar of iron or steel to pass down beside the rivet, and the nib at the end prevents the rod from being displaced by the jar occasioned by hammering. Fig. 688, represents the common smith's pliers or light tongs for picking up small work, or for holding small tools while they are being hardened.

The cutler is also furnished with a variety of chisels, punches, and swages, or *striking* tools, called also *top and bottom* tools, of various forms, and generally in pairs. The bottom tools are usually furnished with square tangs for fitting into the square hole in the anvil; and in using them, the fireman holds the work upon the bottom tool, and above the work he places the top or rod tool, which is then struck by the sledge of the hammer-man. This causes the hot part of the work, which is between the top and bottom pieces of the swage, to rise up and fill the mould formed by them. The top tools are not held by a rigid iron handle, for this would jar the hand, but by hazel rods, prepared for the purpose by being alternately wetted and warmed over a fire in the middle of their length, in order to soften them: that part is then twisted like a rope, and the rod is wound once round the head of the tool, and retained by an iron ferrule or coupler. See Fig. 691.

In the ordinary practice of forging, three processes or modes are adopted.—1, by *drawing down* or *reduction*; 2, by *jumping* or *upsetting*; and the *bending* [illegible]; 3, by *welding* [illegible]. In nearly every case of forging, the first two methods are used, and in many cases all these methods are combined. To reduce the thickness of a bar both in length and in width, the flat face of the hammer is made to fall level on the work; but where the length or the breadth alone is to be extended, the *pane* or narrow edge of the hammer is first used, its blows being directed at right angles to the direction in which the iron is to be spread. When the sides of the object are required to be parallel, and the object is to be reduced in width and thickness, the flat face of the hammer is made to fall parallel with the anvil, as in Fig. 689, or oblique for producing taper pieces, as in Fig. 690; and as action and reaction are equal, the lower face of the work receives the same absolute blow from the anvil as that applied above by the hammer itself. Hence it is not necessary in works of moderate size to present each of the four sides to the hammer, but only two, at right angles to each other. In thus reducing work, much practice in the use of the hammer is required in order to retain the rectangular section. "In converting a round bar into a square with the hammer, the accuracy will depend almost entirely upon the changes of exactly 90 degrees being given to the work, and this the experienced smith will accomplish with that same degree of feeling or intuition which teaches the exact distances required upon the finger-board of a violin, which is defined by habit alone. . . . First, he must acquire the habit of *feeling* when the bar lies perfectly flat upon the anvil, by holding it slackly, leaving it almost to rotate in his grasp, or, in fact, to *place itself*. Next, he must cause the hammer to fall flat upon the work; with which view he will neither grasp its handle close against the head of the hammer, nor at the extreme end of the handle, but at that intermediate point where he finds it comfortably to rebound from the anvil, with the least effort of, or jar to, his wrist. And the height of the wrist must also be such as not to allow either the front or back edge of the hammer-face to strike the work first, which would indent it; but it must fall fair and parallel, and without bruising the work. . . . The flat face of the hammer should not only fall flat, but also centrally upon the work; that is, the centre of the hammer, or that point the principal force of the blow is concentrated, should fall on the centre of the bar, otherwise the edge of the work to which the hammer might lean would be the more reduced, and consequently the parallelism of the work would be lost. It would also be bent in respect to length, as the thinned edge would be more elongated, and thence convex; and when the blows were irregularly scattered, the work would become twisted or put in winding, which would be a still worse error."[1] Suppose it were required to *draw down*, or reduce six inches of the end of a square or rectangular bar of iron or steel: the smith places the bar across the anvil, with the point

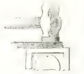

Fig. 689.

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[1] Holtzapffel, Mechanical Manipulation.

the bar being overhung, and not resting quite flat, but tilted up about a quarter of an inch at the near side of the anvil, as in Fig. 688, but less in degree, and the hammer will be made to fall as there shown, only at a very small angle with the anvil. Having given one blow, he twists the work a quarter turn, and strikes it again: he then draws the bar an inch or so towards him, and gives it two more similar blows, and so on until he arrives at the extreme end, when he begins again. The descent of the hammer, the *drawing* the work towards himself, (which Mr. Holtzapffel suggests may be the origin of the term,) and the quarter turn backwards and forwards, all go on simultaneously and with some expedition. At other times the work is drawn down over the beak-iron, and then it is of less consequence at what angle the work is held or the blows given. In smoothing off the work, the position of Fig. 689 is assumed; the work is laid flat upon the anvil, and the hammer made to fall horizontal.

Fig. 689.

The ordinary hand-hammer is shown in Figs. 689, 690, but the Sheffield cutlers and most tool-makers prefer a hammer without a pane, and with a handle quite at the top, the two forming almost a right angle, or from that to about 80°; in some cases [see FILE] the head is bent like a portion of a circle.

In drawing down the tang or taper point of a tool, the extreme end of the iron or steel is placed a little beyond the edge of the anvil, as in Fig. 690, to prevent the anvil from being indented, and the small irregular piece beyond the taper is not cut off until the tang is completed. Fig. 691 shows the position of the chisel in cutting off the finished object from the bar of which it formed a part: the work is placed between the edge of the anvil and that of the chisel, the two edges acting as a pair of shears. A *set-off* is made by placing the intended shoulder at the edge of the anvil: the blows of the hammer are effective only where they are opposed to the anvil, the remainder of the bar retaining its full size, and sinking down, as in Fig. 692.

Fig. 692.

The subject of forging is a very extensive one, and the reader who desires to study it fully ought to consult Mr. Holtzapffel's work. Some further illustrations will be given under FORGING and WELDING; our present object being to state enough to make intelligible the following particulars respecting cutlery.

In the forging of a table-knife, the blade is first produced at the end of a bar of shear steal, and then cut off: it is next welded to the extremity of a rod of iron about half an inch square, and a portion of this is cut off sufficient to form the bolster or shoulder together with the tang. The proper size and shape of the bolster are formed by means of a couple of swage tools. The blade is then heated a second time, and properly finished on the anvil: this is called *smithing* the blade. The maker's mark is stamped upon it, and it is then hardened, by being raised to a red heat and plunged perpendicularly into cold water. It is tempered to a blue colour, and then sent to the grinder.

In the manufacture of steel goods the processes of hardening and tempering perform an important part. Steel possesses the useful property of becoming hard when suddenly cooled from a red heat by being plunged into cold water or oil. By this process, however, it is not only made hard, but brittle; and it is to remove this brittleness that the process of tempering is adopted, which consists in heating the hardened steel articles to a moderate degree. But in proportion as the heat is increased, the hardness diminishes, and when it is reduced to the proper degree of hardness required by the instrument, it is again suddenly cooled by plunging it into cold water. The proper degree of hardness is ascertained by the colour of the film of oxide which forms when steel is slowly heated in the air to a temperature of not less than 430° Fahr. Where elasticity is required, as in springs for watches, gun-locks, &c., the steel is cooled as soon as it has assumed a fine blue. When a keen edge is required, as in razors, the edge is brought to a fine straw colour, while the back is blue. The following table, by Mr. Stodart, shows the colour of the films, the temperatures at which they are produced, and the instruments to which the different kinds of temper are applicable:—

1. Very pale straw yellow	430	The temper required for lancets.
2. A shade of darker yellow	450	A little softer, for razors and surgical instruments.
3. Darker straw yellow	470	Penknives.
4. Still darker straw yellow	490	Chisels and shears for cutting iron.
5. A brown yellow	500	Axes and plane-irons.
6. A yellow, tinged slightly with purple	520	Table-knives and cloth shears.
7. Light purple	530	Swords and watch springs.
8. Dark purple	550	
9. Dark blue	570	Small fine saws.
10. Paler blue	590	Large saws, the teeth of which require to be set with pliers, and sharpened with a file.
11. Still paler blue	610	
12. The same, with a tinge of green	630	Too soft a temper for steel instruments.

Sir Humphry Davy proved that the presence of oxygen is necessary to the production of these colours, by heating bright polished steel in a glass vessel full of nitrogen; in which case coloured films were not produced. According to Nobili, these coloured films are not oxides, but a combination of carbon with oxygen, which, becoming fixed in some way upon the steel, in the form of a thin plate or film, has the effect of preserving the metal from rust. Nobili argues that if this tint were the effect of oxidation, it would not prevent but accelerate oxidation. In order to show the preservative effect of this film, two steel plates of the same quality and polish were selected, one of which was coloured by the usual process, and both were exposed for a month in the open air during a rainy autumn. At the end of this time, the uncoloured plate was covered with rust: the other plate had lost a little of its colour, but was free from rust.

The various forms and sizes of knife, such as the shoemaker's knife, the bread-knife, &c., are forged in the same manner as the table-knife. The penknife blade, which ought to be of the best cast steel, is forged from the end of a steel rod, with a light hammer, upon a small anvil; and as much is cut off as is necessary to form the joint. The blade is then held in a pair of tongs, and heated a second time; the joint part is next finished, and a temporary tang drawn out for driving into a small haft or handle for the grinder, as shown in Fig. 693. The nick or notch called the *nail-hole* is stamped by means of a chisel, while the blade is hot. The blade is hardened by raising it to a red heat, and dipping it in water up to the shoulder. The tempering is performed on a number of blades at a time, arranged side by side, with the back downwards, upon a flat iron plate, placed over the fire, and left until the proper colour has been attained.

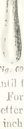
Fig. 693.

Forks are sometimes made of cast metal, but the better kinds are forged from a rod of steel about $\frac{3}{8}$ inch square: the tang, shoulder, and shank are first roughly formed, and then cut off, leaving at one end about an inch of the square part of the steel, which is afterwards drawn out flat to about the length of the prongs. This *mood* or *mould*, Fig. 694, is heated until it becomes soft, and placed in this state in a steel boss, or die, upon which a second boss attached to the lower surface of a heavy block of metal is made to fall from the height of several feet:[1] in this way are formed the prongs and central part, or *bow*, of the fork; the thin film of steel which is left between the prongs is cleaned out with a file. The fork is then ground and finished, and is ready for hafting.

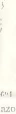
Fig. 694

Razor blades ought to be forged out of bars of the very best highly carbonated cast steel, tilted to about $\frac{1}{2}$ an inch in breadth, and of a thickness sufficient for the back of the razor. The blade is first moulded at the end of the porter rod, and then forged, and the edge being brought out, the concave surface is formed by working the side on the rounded edge of the anvil; it is then cut off, and the tang is either drawn out from the same material as the blade, or, if this be of superior quality, a piece of iron is welded to it. The steel ought to be of excellent quality to undergo the beating necessary to produce the thinner part, while the back is left thick. Some workmen are so expert in forging the blade, that they will produce on the anvil an edge so sharp and even, that it can be used for shaving after being whetted. After forging, the blade is *smithed*, or beaten on an anvil, to make the metal as compact as possible; a process adopted with all the better kinds of cutting instruments. The blade is also slightly ground or *scorched*, after the forging, on a dry coarse grit-stone, in order to bring it to the shape required, and also to remove the black scale or coating which prevents the uniform action of water and heat in the process of hardening and tempering. [ANNEALING.] The blade is drilled for the joint, and stamped with the name; it is hardened and tempered; then ground on a wet stone of from 4 to 8 inches in diameter; the shoulders of the blade are in some cases ground on a fine, dry stone, for which purpose the edge of the stone is rubbed with bee's-wax, to prevent the stone from crumbling away: the blade is next lapped on a lead lap, which gives the true curve to the surfaces: the tang and back are glazed on a leather glazer; the blade is next polished on a soft buff wheel covered with dry crocus, revolving slowly, and, lastly, it is handled and set. This completes the processes concerned in the manufacture of a razor blade; the best penknife blades and scissors are treated in a similar manner; but some of these processes require a more detailed notice, and we will return to them after noticing the forging of one or two other articles.

There is, perhaps, no article in cutlery that varies so much in price and quality as scissors; for while some are sold at the low rate of $3\frac{1}{2}d.$ per dozen pair, others produce ten guineas and upwards the single pair, and between these extremes the prices vary according to the value of the metal, and the amount of labour bestowed upon the handle. The best scissors are made of cast steel, and are hardened in the blades, shanks, and bows. Shear-steel scissors, which are in most common use, have the blades only hardened. A third variety, called *steel scissors*, have steel blades, but the bows and shank are of iron. Large scissors, such as tailors' shears, are of this kind. It was formerly the practice, in order to economize the more costly material, steel, to make all large shears entirely of iron, with the exception of a slip of steel welded along the edge of the blade. The best description of iron scissors are falsely named *run* or *virgin steel;* they are formed of good cast-iron, while the cheapest description of scissors are made of common cast-iron in very large quantities for South America and the Indies. The most costly scissors have their shanks and bows of gold, silver, &c.

The varieties of scissors are very numerous, such as *button-hole scissors, cutting-out, drapers', flower, garden,* and *grape scissors, horse trimming scissors; hair, lace, lamp, nail, paper, pocket, stationers'*, and *tailors' scissors,* and many others. The following general description refers to a pair of common steel scissors of good quality.

In forging steel scissors a single blade is formed at the end of a small bar of flat steel, and is then cut off together with enough of the metal to form the shank and bow. A hole is then punched through the projecting lump of metal sufficient to admit the point of a small anvil, or *bick-iron*, upon which the bow is worked out with the hammer. The bick-iron is furnished with a shallow groove, for rounding the inside of the bows. The smallest kinds of scissors are cut in this way [illegible] with surprising dexterity and despatch, the result of long practice. After being *lighted*, or softened in the fire, the shank and bow are improved in shape by filing, the joint is squared, and the hole is bored and fitted for the rivet. The blades are next ground; after which the bows and ornamental work are smooth-filed and burnished with fine emery and oil. The blades are forged chiefly by eye, without reference to their being in pairs: the separate blades are, therefore, next sorted into pairs, screwed together, and made to "walk and talk" well, as the "putter-together" calls the smooth motion of the blades. The screw which unites the two blades consists of three parts differing in diameter; viz. the *head*, the *neck*, and the *thread;* the bottom of the countersink that receives the head of the screw is called the shelf or the *twitter bit*. Each pair is then bound round with fine iron wire, the rivet is taken out, and the blades and shanks are hardened. When the wire is removed, the blades are ground into proper shape, again fastened together, and made to work properly. The bows and other parts are rubbed up with fine emery and oil, and the scissors are taken a third time to the grinder; the shanks are ground, and the whole instrument glazed and polished. When put together again, the edges of the blades are whetted, and the scissors are lastly handed to women who fine burnish the parts requiring it, with polished steel tools. Well-made scissors sometimes appear to grate a little when closed: this arises from the presence of dirt or dust, for if the finger be passed along the edges so as to remove it, the smooth and pleasant action of the scissors will be restored.

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[1] The arrangement of the stamping press is shown in Fig. [illegible], p. [illegible], *ante*.

The blades of scissors must be in close contact at the time of cutting, otherwise the substance to be cut will fold down between them, especially if it be very thin. When the blades exactly meet, one serves to support the material, while the other severs it, or rather each blade supports the material for the other to cut. The blades are not made quite flat on their faces, or with truly plane surfaces, (as in Fig. 695, which is an imaginary longitudinal section of the instrument,) because, in such case, the friction would be greatly increased by the rubbing of the surfaces. "The form really adopted more resembles the exaggerated diagram, Fig. 696; the blades are each sloped 2° or 3° from the plane in which they move, so that their edges alone come into contact; instead of the blades being straight in their length they are a little curved so as to overlap; and close behind the screw pin by which they are united, there is a little triangular elevation, insignificant in size, but most important in effect, which may be considered as a miniature hillock or ridge sloping away to the general surface near the hole for the screw. This enlargement, or bulge, is technically called the *riding part*, and as there is one on each blade, when the scissors are opened so that the blades are at right angles, the points or extremities only of the riding parts come into contact, and the joints may then have lateral shake without any prejudice. But as the blades are closed, first the bases or point of the riding parts, and lastly the summits or tops, rub against each other, and tilt the blades beyond the central line of the instrument; the effect of which is to keep the successive portions of the two edges in contact throughout the length of the cut, as by the time the scissors are closed, the points of the blades are each sprung back to the central line of the scissors, which is dotted in Fig. 696. Although scissors when in perfect condition for work may be loose or shake in the joint, (and thereby placed beyond their range of action,) they will be always found to be tight and free from shake as soon as the blades can begin to cut the material near the joint, and so to continue tight until they meet at the points. That all scissors do exhibit this construction may be easily seen, as when they are closed and held edgeways, between the eye and the light, they will be found only to touch at the points and at the riding parts, or those just behind the joint screw, the remainder being more or less open and gently curved; and their elastic action will also be experienced by the touch, as whilst good scissors are being closed there is a smoothness of contact which seems to give evidence of some measure of elasticity."[1]

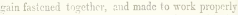
Fig. 695.

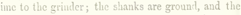
Fig. 696

Fig. 697 shows the section of one blade of a pair of scissors registered in 1841 by Mr. G. Wilkinson of Sheffield. Here the elastic principle is introduced differently. Instead of the riding part, one blade is perforated immediately behind the screw for admitting freely a small pin or stud, *s*, fixed to the end of a short and powerful spring, so that the stud, *s*, acting on the opposite blade, throws the points of both blades towards each other, so as to give them a tendency to cross, but this being resisted by the edges of the blades touching each other, they are kept in contact throughout their motion, and produce their cutting effect well and agreeably.

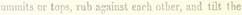
Fig. 697.

The grinding and polishing of cutlery form an important part of the operations carried on at Sheffield. They are usually conducted in buildings called *wheels* or *mills*, each of which is divided into separate rooms called *hulls*, and in each hull are six *troughs* with a grindstone and a polisher in each. Motion is communicated to the stones by means of a steam-engine. The most celebrated of these grinderies is the Castle Mill, situated near the junction of the Sheaf and the Don. A view of it is given in one of our large engravings. Its castellated appearance has given it a name, and it comprises a central court-yard, with buildings running along the four sides, containing numerous apartments occupied by the grinders, who contribute each a certain sum for rent

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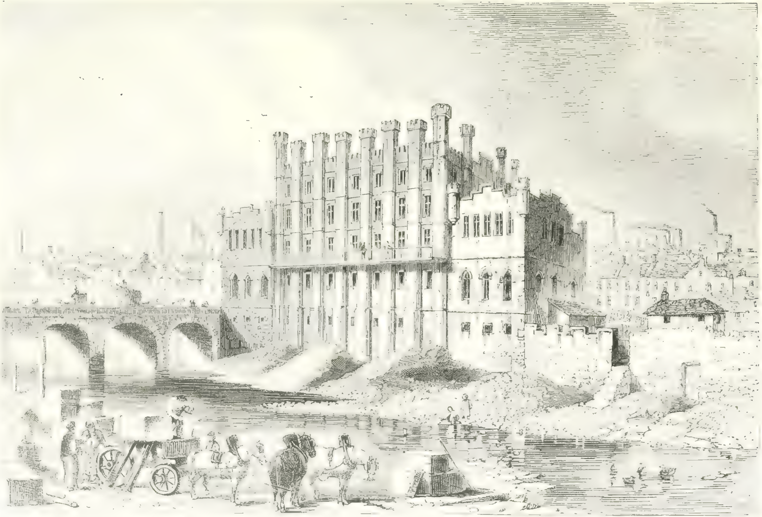
[1] Holtzapffel.



CUTLERY.—EXTERIOR VIEW OF THE CASTLE GRINDING MILL AT SHEFFIELD.

and for steam power. The stones vary in quality and size with the article to be ground. They range from 6 to 24 inches in diameter, and are fixed upon square iron spindles from 12 to 30 inches long, terminating in steel-pointed centres: the stone is wedged fast near the right hand extremity of the spindle, and near the left is fixed the pulley for the driving belt. The spindle is supported on two long pieces or sleepers united at their extremities and resting on the ground; near one end are two upright posts, at the upper parts of which are hollow centres for the spindle to run in: the centres are of lignum vitæ, horn, or steel. The Sheffield grinders commonly use ash for the centre blocks. Between the standards and below the stone is a long narrow water trough of wood lined with lead or iron, called the *dyppan*: it is not allowed to contain water enough to reach the stone, or it would be splashed about by the centrifugal force; but the water is thrown upon the stone from a bucket with the hand, or is allowed to flow in a thin jet upon the side of the stone. The man sits astride a board called the *horse*, which admits of being shifted to or from the stone. The edge of the horse near the stone is commonly shod with iron, for supporting the tool used in "turning-up" the stone. A splash-board, or some other contrivance, is erected on the other end of the trough, projecting above the top of the stone so as to catch most of the water that flies off and return it to the trough. [See GRINDSTONE.]

Saws, fenders, &c., which present a large extent of surface, require stones of great diameter; while razors and the smaller articles of cutlery are ground upon small stones. Saws, scythes, and edge tools which require a certain temper, are ground on a wet stone, for which purpose water is kept in the trough to such a height as just to touch the stone. An extensive class of small articles, such as razors, scissors, pen and pocket-knives, forks, needles, &c. are ground upon a dry stone. Dry grinding is a more expeditious operation than the wet, but several articles of cutlery are first ground on a dry stone, and afterwards on a wet one. Fork grinding, however, is always performed on a dry stone, and hence the peculiarly destructive character of this branch. Dr. Holland, a physician of Sheffield, declares the fork grinder's employment to be probably more destructive to human life than any other pursuit in the United Kingdom. "In the room in which it is carried on there are generally from eight to ten individuals at work, and the dust which is created, composed of the fine particles of stone and metal, rises in clouds, and pervades the atmosphere to which they are confined. The dust which is thus every moment inhaled, gradually undermines the vigour of the constitution, and produces permanent disease of the lungs, accompanied by difficulty of breathing, cough, and a wasting of the animal frame, often at the early age of twenty-five. Such is the destructive tendency of the occupation, that grinders in other departments frequently refuse to work in the same room, and many sick clubs have an especial rule against the admission of dry grinders generally, as they would draw largely on the funds, from permanent and long continued sickness."[1]

It is shown from the statistics of the trade, that the average age of fork grinders does not exceed thirty years, and Dr. Holland shows that while in the United Kingdom 296 persons out of 1,000 die annually between the ages of twenty and forty, 885 fork grinders perish out of the 1,000!

A complete remedy for the evil consists in the thorough ventilation of the fork grinder's apartment by means of a ventilating shaft containing a revolving fan. A wooden funnel from ten to twelve inches square is placed a little above the surface of the revolving stone, on the side the furthest from the grinder, which funnel terminates in a channel immediately under the surface of the floor. The channel varies in length according to the situation of the grinder in reference to the point where it is most convenient to get rid of the dust. If eight or ten grinders work in the same room, each has his own funnel and channel, and these all terminate in one large common channel situated close to the wall of the apartment. Within this general channel is placed a fan similar to that used in winnowing corn, and to this is attached a strap which passes upwards and over a pulley, so that whatever puts the pulley in motion, causes the fan also to revolve. The pulley is placed in connexion with the machinery which turns the stone, so that whenever the grinder adjusts his machinery to work, he necessarily sets the pulley and the fan in motion. The fan acting at this point, whatever may be the length of any of the subordinate channels, causes a strong current to flow from the mouth of each funnel, which carries along with it all the gritty and metallic particles evolved, leaving the room in which the operations are pursued, free from any perceptible dust. When the whole apparatus is perfect and in excellent condition, the atmosphere of the place is almost as healthy as that of a drawing-room.

Dr. Holland mentions that in one manufactory, the dust is conveyed by the general channel into a trough of water outside the building. The quantity which accumulates in it in a few weeks is very great; and in raising it in a mass, it seems to have almost the specific gravity of metal. The first cost of the apparatus would scarcely exceed the proportion of a sovereign for each grinder; the funnel may be had for a few shillings, and the fan and pulley for a mere trifle. "Were the legislature to interfere, and make it imperative on the part of the proprietors of wheels, to construct such an apparatus, and compel them to keep it in a perfect condition, an immense amount of disease, suffering, and wretchedness, would be prevented; and the future inquirer into the condition of grinders would not have to record the numerous premature deaths." In places where the

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(1) "The Vital Statistics of Sheffield," by G. Calvert Holland, Esq., M.D. London, 1843.

"Diseases of the Lungs from Mechanical Causes," by the same. 1843.

apparatus had been in operation for years, Dr. Holland did not find a single individual labouring under any pulmonary affection; and in other instances where the lungs had become affected with disease, the erection even of an imperfect apparatus by the artisans themselves, arrested the disease, and afforded substantial relief. [See NEEDLE.]

In grinding articles of cutlery, the size of the stone is of importance. If ground upon a large stone, revolving with great rapidity, the grinding will be performed more expeditiously than on a smaller stone moving at the same rate; but the steel is often thereby, by overheating, deprived of some of its excellent qualities, which no subsequent operation can restore. The concavity on the surface of a blade also depends upon the size of the stone: thus a stone four inches in diameter, must give to the blade a corresponding concavity, or a curve of two inches radius; and such a curve will evidently yield a keener edge than can be produced from a six, eight, or twelve inch stone, because the smaller the diameter the more convex is the stone, and the more concave will be the blade which is ground upon it. Mr. Ebenezer Rhodes, of Sheffield, a practical cutler, in his "Essay on the Manufacture of a Razor," enumerates the qualities of a good razor to consist in a proper form, weight, and justness of proportion, with proper hardness, regularity, and fitness of concavity. The stones used in producing this concavity of surface vary from four to twelve inches in diameter, according to the price of the article required. A four-inch stone is most generally used; but Mr. Rhodes recommends a stone of from six to eight inches in diameter, which produces razors "sufficiently hollowed or ground out for any service, however hard, to which they may be applied; and they combine a desirable strength and firmness of edge, with a requisite degree of thinness. The concavity of a razor should likewise possess great evenness and regularity, otherwise a very unequal edge is produced; a defect which every application to the hone will rather increase than diminish, and which nothing but re-grinding in a more perfect manner can possibly remove."

Figs. 698 to 703 will show some of the forms which have been given to razors. The proportion between the width of the blade and the thickness of the back is such that when the blade is laid perfectly flat on the hone, so that the edge and back both touch it, the proper angle is obtained, which varies from about 17° to 20°. In the enlarged figures the angle of 18° is preserved throughout, as shown by the dotted line, and the concavity of each side of the razor is shown within the angle thus formed. The chief use of this hollowing out of the sides is to avoid the necessity of sharpening the entire side of the wedge formed by the dotted lines. It would evidently be much more tedious and difficult to wear down the flat sides represented by the dotted lines than the small portion of the same which is left; and even if it were attempted, the edge would probably be rounded instead of flat. The concavity, therefore, assists in making the razor on the hone, it makes the edge thinner, leaving but little for the stone to wear away, and it prevents the polished and finished surface from being injured during the sharpenings.

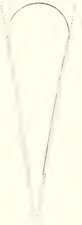
Fig. 698.

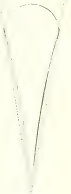
Fig. 699.

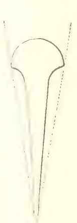
Fig. 700.

The most common forms of razor are shown in the sections, Figs. 698, 699; the one having been formed by grinding transversely on a wheel of 4 inches diameter, and the other on one of 12 inches, the general extremes of curvature. Fig. 700 is produced by grinding the blade lengthways on the stone, so as to become nicked in, and thus produce any degree of thinness required. When used on a strong beard a considerable vibration is produced, which has led the Sheffield cutlers to apply the term *rattler* to these razors. In Fig. 701 the two modes are combined, the razor having been first ground transversely, as for Fig. 699, and then lengthways, so as to be nicked in for about half its width: these are called *half-rattlers.* In another form, Fig. 702, a very thin, acute blade has been fixed in a detached back, something like a dove-tail saw. Fig. 703 is a guarded razor, a loose frame or guard of brass being added to the blade; it is intended to prevent the edge from penetrating to any serious depth when the razor is used by nervous or infirm persons. The setting of razors will be noticed under HONE: our present business being with their manufacture.

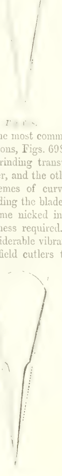
Fig. 701.

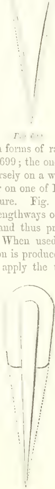
Fig. 702.

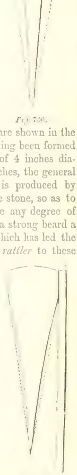
Fig. 703.

The grinders have various contrivances for protecting their hands from the heat excited by the friction. Table knives are for this purpose fitted in a wooden case, as shown in Fig. 704.

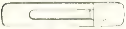

Fig. 704.

After the articles of cutlery have been ground, they are *lapped*, *glazed*, and *polished* on metal or other wheels, called *laps*. The cutler's narrow, cylindrical lap consists usually of a wooden centre, made in 1 or more pieces, the grain of the wood pointing to the axis in order to preserve the circular form, and united by circular disks of wood or metal; the edge is then turned to the required width, with a groove in the centre, and a chamfer on each edge for holding the metal rim; this is usually 1 part tin, and 4 or 5 of lead, (the lining of old tea-chests being preferred,) and is attached to the centre by casting; the edge or *face* is then turned true, after which it is dressed with emery and oil, a number of fine grooves being made on the face in order to retain the dressing or *head*, as it is called. It is brought to a uniform surface by drawing the work, such as a razor blade, from end to end steadily across the revolving lap. When a dozen blades have been prepared in this way, the process is repeated with fine emery, or the lap is *fined* by rubbing the head with a piece of felt, then with a smooth piece of flint, or with a steel blade. In finishing the blades a stick of charcoal is also used to deaden the emery before the flint is applied. In lapping penknives and small articles, the wheel is charged by rubbing on it a lump of emery cake. A white colour is produced on steel with a coarse lap and heavy pressure of the work upon it; but with a fine lap and light pressure, gradually drawing the work from one end to the other, a black polish is produced.

Wood wheels, called *glazers*, are also used; they are arranged in 6 or 8 pieces, so that the edge or face may be entirely formed of the end grain of the wood. Mahogany is preferred, but walnut, oak, crab-tree, and birch, are used. These wheels are mostly fed with emery cake.

Polishing wheels with wooden centres covered with leather are also used. For polishing razors and fine cutlery the leather is charged with crocus, and the wheel is always used dry. Both the polisher and the blade must be moderately heated, or a good polish cannot be produced; the heat is usually supplied by the friction of the surfaces. The polisher is made to revolve much more slowly than other wheels, and the blade is moved to and fro from end to end very quickly and with considerable pressure, by which means the heat is equally distributed: the blade is not drawn slowly across, and off, as in lapping, but is moved end-long, and is pulled off quickly. The man's fingers are protected from the heat of the blade by a thick piece of cloth or felt, which is also used to supply the polisher with crocus by dabbing it upon the dry powder, and then rubbing it upon the polisher.

The handles and hafts of the various articles of cutlery are furnished by the cutler. The materials for handles are very numerous, but that which is most used is elephant and walrus ivory. Other substances in request are German and Indian stag-horn, buffalo and cow-horn, tortoiseshell, mother-of-pearl, coco-wood, snake-wood, &c. Stamped gold and silver are also used. Articles in such common use as knives and forks are best handled by nailing flat pieces of bone, ivory, or wood, upon a flat piece of iron continued from the blade. A very good method is what is called *Through-tang*, that is, to drill a hole completely through the handle, and to insert a cylindrical or four-sided prong projecting from the blade, riveting it at the opposite end. A common method is to pass the small prong projecting from the blade about half-way into the handle, and to secure it with melted resin mixed with fine ashes or with whiting, in order to improve the colour. Such a handle, however, readily becomes loose when put into hot water. Balance handles are made by perforating the haft deeper than usual, and then dropping in a small piece of lead; the handle is thus heavier than the blade, which, being furnished with a projecting shoulder, is prevented from touching the table-cloth when laid down. Messrs. Joseph Rodgers & Co., at whose establishment at Sheffield the Editor has witnessed many of the processes described in this article, have lately registered a method of fixing a knife blade in the handle, which renders its removal, or its becoming loose by ordinary wear, impossible. It is secured entirely by mechanical means, without any kind of cement, as shown in Fig. 705, in which it will be seen that in addition to the hole for the reception of the tang, a slight recess is cut out on one side, into which the end of a small spring, riveted or otherwise fastened to the tang, falls, and thus secures the two portions firmly together. When the spring is fastened to the tang, the end of the latter is simply inserted into its hole, and the moment the detaining end of the spring clears the notched edge of its recess, it falls in, and acting like a ratchet detent, no force, short of that of fracture of the parts, can separate them. The consumption of ivory for handling table knives and forks is very large. The teeth are cut up by means of a circular saw, a very strong ammoniacal odour being developed by the friction. The methods of preparing HORN and TORTOISESHELL will be noticed under these heads.

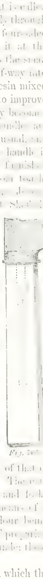

Fig. 705.

There is probably no article of cutlery in which the processes are more numerous than in a penknife, one with three blades having to pass through the finisher's hands about 100 times. When the blades, spring, and *scales*, as the iron plates at the side are called, are severally bored with appropriate holes, they are all pinned together, loosely at first, till all the parts fit and work properly together; they are then riveted with bits of wire with a hammer on a small anvil. The sides of horn, ivory, or shell, are filed and scraped, and then polished twice on the buff. The backs of the springs are glazed.

For letting in a *shield*, *escutcheon*, or plate of silver on one side of the handle, a cavity is cut out by means of pattern plates, or *templets* of hardened steel, pierced with the exact form of the shield. The cutting tool, Fig. 706, is like the ordinary breast-drill, Fig. 707, 8 or 10 inches long, and like it, is used with the breast-plate, Fig. 709, and drill-bow, Fig. 708; but the extremity of the tool is cleft, or made in two branches, which left to themselves spring open to the extent of an inch or more. Each half of the tool has a shoulder or stop, which bears upon the surface of the guard-plate, and a rectangular cutting part which protrudes through the shield-plate as far as the required depth of the recess, and is shaped both at the ends and at the sides, or at the ends only. [See DRILLS.] When this elastic tool, or spring-passer, has been compressed so as to enter the guard-plate, it is put in motion, and flounders about in all directions as far as it can expand, and thus routs or cuts out the shallow recess. The shields having been punched out, are fixed in by a couple of rivets, and smoothed off.

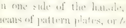
Fig. 706

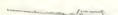
Fig. 707

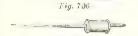
Fig. 708

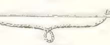
Fig. 709.

Handles of ivory, shell, &c. are sometimes dotted all over with little studs of gold and silver; the holes for these are first drilled from thin pattern plates of brass or steel, in which the series of holes have been carefully made. The drill or passer, Fig. 707, has an enlargement or stop, which by coming in contact with the surface of the pattern plate, prevents the point of the drill from penetrating beyond a certain depth into the handle. The holes are then filled with silver or gold wire, which is either filed and polished off level with the general surface, or allowed to project as small studs.

CYANOGEN, a gaseous compound of carbon and nitrogen, (NC_2, or Cy,) named from κυανος, *blue*, and γεννάω, *I generate*, on account of its being necessary to the formation of *Prussian blue*. It is interesting as forming a perfect type of a salt-radical. It may be prepared by heating in a small glass retort cyanide of mercury, well dried and powdered: metallic mercury is produced, and cyanogen—a colourless permanent gas, which must be collected over mercury, as it is very soluble in water. It has a pungent and peculiar odour, something like that of peach-kernels or hydrocyanic acid: it is condensed by the pressure of 3.6 atmospheres into a thin colourless liquid. Cyanogen burns with a beautiful purple or peach-blossom coloured flame, producing carbonic acid, and giving off nitrogen. Its sp. gr. is 1·8064.

The interest belonging to this subject is chiefly chemical. Under the head, PRUSSIAN BLUE, the chief compounds of cyanogen used in the arts will be noticed. The compound of hydrogen and cyanogen, cyanide of hydrogen, or hydrocyanic or prussic acid, (CyH,) is one of the most deadly poisons known.

CYCLOID (from a Greek word signifying, *like a circle*), a term not very accurately applied to a curve which is traced out by any point of a circle rolling on a straight line. As the wheel of a carriage revolves, each nail on the circumference describes a succession of cycloids. The properties of the cycloid will be noticed under PENDULUM.

CYLINDER, (κύλινδρος,) a straight line moving round the circumference of a circle, keeping always at right angles to its plane, will describe what is called a *right cylinder;* if the moving line be oblique to that plane, it is called an *oblique cylinder*. The uses and applications of the cylinder and of cylindrical surfaces in the arts are exceedingly numerous and very important.

DAMASCUS BLADES. See GUN BARRELS.

DAMASK, a textile fabric, variegated with figures of flowers, &c., woven in the loom. The manufacture is said to have originated at Damascus, whence the name. See WEAVING.

DAMASKEENING. See BRONZING.

DEALS are boards of fir, above 7 inches in width, and exceeding 6 feet in length. If less than 7 inches wide, they are called *battens*, and if less than 6 feet in length, they are called *deal-ends*. Deals are imported into the United Kingdom from Dantzic, Petersburg, Narva, and many other ports in the Baltic, and from North America; but those from Christiania, the capital of Norway, are the most esteemed. Their superiority is said to depend on their being more perfectly sawed than other deals; but it is really due to the quality of the timber, and the care with which the sapwood and other defective portions of the timber are cut away. See **WOODS**.

DECANTATION. In order to separate a fluid from the finely divided solid matter which it may contain, the solid matter is allowed to settle down, and the fluid portion is then removed. This is called *decantation*, and it is in many cases far superior to *filtration*. The fluid may be poured off by hand, and as much as possible removed without disturbing the deposit; but it is usually much better to use a syphon. In the manufacture of smalt, [see COBALT,] the process of decantation is largely resorted to. See also EMERY, &c.

DECLINATION, or VARIATION OF THE MAGNETIC NEEDLE, is the angle which the horizontal needle makes with the geographical meridian of any place. See COMPASS.

DECOCTION. It may be useful, thus early, to describe a few of the processes used in chemistry and the chemical arts for effecting the solution of different substances. When hot water is poured upon a substance, and left to act upon it for a short time, the process is called *infusion;* but when heat is kept up for some time by the application of fire, the process is called *decoction*. The common method of making tea is an example of infusion; and when coffee is boiled we have an example of decoction. When cold or warm water is poured upon a substance, and it is left to stand for some time, the process is called *maceration*. When a soluble body is separated from an insoluble one by washing, the process is called *lixiviation*. "Suppose it were necessary to separate a salt from a quantity of ashes: a funnel of sufficient size should have the lower aperture stopped by a cork, and should be supported on a stand, so that it may steadily retain its proper position. A few pieces of the ash, of such size that they shall not pass through the neck of the funnel, should be introduced in the first place, to prevent the descent of the matter to be placed over it. Having added pieces rather smaller, until the surface exposed in the funnel is an inch in diameter, the rest should be crushed in a mortar to a coarse powder, or rather to small pieces or grains, and put into the funnel above that previously arranged. If the substance be such that it will not afford lumps of sufficient size or strength to remain in the neck of the funnel and support the rest, then its place should be supplied by some pieces of broken glass, which may be continued to the height before mentioned, and which, while they support the substance, afford abundant passages for the fluid when required. Being thus far arranged, hot or cold water is to be poured into the funnel, according to circumstances, its quantity being such that it will just cover the ashes. The whole is to be left in that state for a time proportionate to the solubility of the substances present. The water which has penetrated the fragments will gradually dissolve the salts, and forming a heavy solution, will descend in the free spaces, changing situations with the water not yet saturated. In this way a solution will be produced, of much greater strength below than above, and the upper part of the mass will be washed almost perfectly at the first operation. When sufficient time has been allowed, according to the quantity and nature of the salt, and the manner in which it is enveloped, the cork beneath should be withdrawn, and one-half or two-thirds of the solution suffered to run out gradually, not hastily, lest greater disturbance of the solid matter in the funnel be occasioned than is necessary or advantageous. The cork is to be replaced, fresh water added above, so as not to disturb the arrangement; and being left as before for a time, the second solution should then be withdrawn, and this operation repeated till the water which passes is perfectly free from salts, or contains so little as to make further attention unnecessary."[1]

DECOMPOSITION, the separation of a compound body into its component parts, either spontaneously or by chemical agency. Thus the decomposition of sulphate of iron furnishes sulphuric acid and oxide of iron as its proximate elements, and sulphur, oxygen, and iron as its ultimate elements. By decomposition substances are produced whose properties are essentially distinct from those of the compound. Such is not the case by mere mechanical action, for if a compound be reduced by grinding or other mechanical means to an impalpable powder, its chemical properties still remain unchanged. See ANALYSIS.

DEFLAGRATION is the sparkling combustion of substances without violent explosion, as when charcoal or sulphur is thrown into melted nitre. Glass-stoppled jars, used in the lecture-room, for showing the combustion of different bodies in certain gases, such as phosphorus, sulphur, charcoal, &c. in oxygen, protoxide of nitrogen, &c., are called *deflagrating jars*; the substance to be burnt is inserted by means of a small metal spoon called a *deflagrating spoon*.

DELF, or DELFT, a kind of coarse porcelain originally manufactured at Delft, in Holland. It has been superseded even in Holland itself by the superior manufactures of England and the improved ware introduced by Wedgwood in the making of pottery.

DELIQUESCENCE. Salts which gradually dissolve, or *deliquesce*, by attracting moisture from the air, are called *deliquescent* salts: such are carbonate of potash, acetate of potash, chloride of calcium, &c. Other salts, which give out moisture to the air, are called *efflorescent* salts: thus sulphate of soda, or Glauber's salts, by exposure, spontaneously parts with its water of crystallization, loses its crystalline form, and crumbles down into a white powder.

DENSITY. The proportion of the quantity of matter to the volume, is called the *density* of a substance. Thus if of two substances one contain in a given space twice as much matter as the other, it is said to be twice as dense. The density of bodies is therefore proportionate to the closeness or proximity of their particles, and the greater the density, the less the *porosity*. See GRAVITY, SPECIFIC.

DETONATION, an explosion accompanied by noise. A stout glass tube used in the analysis of gases by firing them with the electric spark is called a *detonating tube*, and the process of firing is called *detonation*. See EUDIOMETER.

DEXTRINE, see BEER—STARCH.

DIAMOND, see CARBON.

DIAPER, a sort of fine flowered linen, used chiefly for table-cloths, napkins, &c. See WEAVING.

DIASTASE, see BEER.

DIE-SINKING. In stamping money and medals the preparation of the die is all important. Details on this subject will be found under COINING, App. Dies for cutting screws also require much care. See SCREW—also CALICO-PRINTING—ENGRAVING.

DIGESTER, a boiler, invented by Papin, closed by a tightly fitting cover, which is held down by a screw *s*, Fig. 710: this cover has two openings, one of which is closed by a stopcock *c*, and the other is furnished with a valve *v*, pressed down by a weighted lever, *l w*. The weight of course acts with greater or less power, according as it is further from or nearer to the fulcrum. This valve is forced open when the pent-up steam has acquired a certain amount of tension, and a portion of it escaping, the temperature and consequently the elasticity of the steam are diminished and the danger of explosion avoided. In Fig. 710, a portion of the side is represented as broken away, in order to show the arrangement of the valve, &c. A common form of digester is called an *autoclave*, Fig. 711, on account of the lid being

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(1. Faraday. "Chemical Manipulation," Section VI.)

self-keyed, whereby it becomes steam-tight by turning it round under clamps or ears at the sides. The use of the digester is to subject certain articles of food, &c. to higher temperatures than can be attained

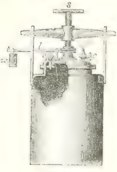

Fig. 710.

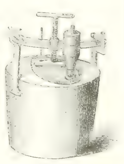

Fig. 711.

when the surface of the boiling liquid is exposed to atmospheric pressure. [See Ebullition.] The increased temperature of water thus produced enables it to separate the gelatine from the phosphate of lime of bones; but the soup made from this gelatine has often an empyreumatic and unpleasant taste. See Bone—Gelatine.

DIMITY, a stout cotton cloth ornamented either with raised stripes or figures, and employed white for bed and bedroom furniture.

DISTILLATION, a process by which one body is separated from another by means of heat, in cases where one of the bodies assumes the elastic form at a lower temperature than the other: the first rises in the form of vapour, which is received and condensed in a separate vessel. When the vapour condenses in the solid form, such as sulphur, calomel, &c., the process is termed Sublimation. [See Arsenic—Camphor—Sulphur.] In this case, the substance to be distilled is usually placed in the lower part of the vessel to which heat is applied, and the vapour rising to the upper and cooler part adheres to it; or an upper vessel being inverted over the lower one, the vapour is condensed within it in the form of a solid cake. When, however, the condensed vapour is obtained in the liquid form, the arrangements are different. The vapour must be preserved in its elastic form up to a certain height, at which the neck of the vessel turns by a sharp curve or an elbow, so that after the vapour has been condensed into the liquid it may descend as quickly as possible. The height of the elbow above the point where the heat is applied, must be only just sufficient to prevent the mass below from boiling over the neck. When the neck of the lower vessel is of great length, the escape of heat must be prevented either by giving it a polished surface, or by covering it with some non-conducting body. The vessel used for generating the vapour, if of large size, is called a *still*. Distillation as carried on by the chemist is usually by means of *retorts*, and the vessel that receives the distilled matter is called a *receiver;* this is perhaps the most simple method of distilling; but it can generally be conducted only in a small way, and when the vapour is easily condensible or when a moderate heat is applied.

Fig. 712 shows a common laboratory arrangement for distillation with a glass retort and receiver. In order to produce a complete condensation, the neck of the retort is covered with linen or bibulous paper, kept constantly wet by cold water dripping upon it

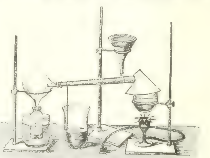

Fig. 712. FARADAY'S ARRANGEMENT.

from a funnel or filter: a few threads of twisted tow draw off this water into a basin. The contents of the retort are vaporized by means of the gas-flame; and the vapour passing along the neck may be wholly or partially condensed: any vapour which escapes condensation passes into the cooled receiver, where it is condensed; the bottle containing the distilled product being surrounded with water, or, if necessary, with a freezing mixture.

Liebig's condenser, shown in Fig. 713, consists of a slightly conical glass tube, 18 or 20 inches long, and of a diameter of about 1½ or 2 inches at one end and an inch or less at the other: this is enclosed water-tight in a wider and shorter metal tube, to the lower end of which is attached a funnel supplied with a small current of cold water from a cistern above. As the cold water enters the bottom of the tube, it gradually ascends, and becomes warmed by condensing the hot vapours; and having performed its useful office of keeping the tube cool, it drips or flows off, according to the supply from the cistern, by the hanging tube. The whole arrangement will be evident from an inspection of the figure.

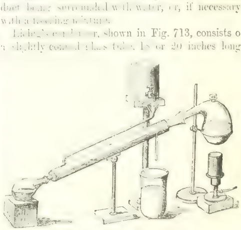

Fig. 713. LIEBIG'S ARRANGEMENT.

The still is usually so arranged as to present a large surface to the fire. For this purpose it is commonly made in the form of a frustum of a cone, the base being as large as it can conveniently be made, and the height small. The neck should be wide enough to convey away the vapour as fast as it is formed: the height of the neck must be regulated by the nature of the substance. If it be mucilaginous, such as the wash from which spirit is distilled, the neck should be longer, to prevent its boiling over. The end of the descending part of the neck is inserted into a spirally twisted pipe called the *worm* The worm is contained in a worm-tub, about 6 or 8 times the capacity of the still. The worm enters on one side of the tub at the top; it then passes spirally in about 6 or 8 convolutions to the bottom, where it comes out of the side in order to discharge the liquid arising from the vapour condensed within it by means of the cold water with which the tub is filled. The water is kept cold in the tub by the warm water flowing away from the top whilst a supply of fresh cold water is admitted at the bottom. It is of importance to keep the worm as cool as possible, because the object is not merely to condense the vapour, but to cool the liquid resulting from it, in order that it may be less liable to evaporation after coming over. Fig. 714 shows a common form of still, in which s is the still, H the head w the worm, and R the worm-tub or refrigerator.

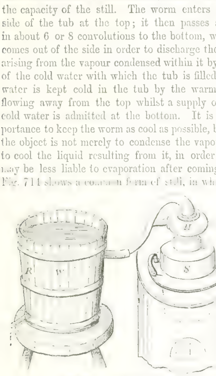

Fig. 714 THE COMMON STILL.

The arrangement of the fire for heating the still is of importance. The fire should be so placed upon a grate that a due supply of air be admitted to excite a vigorous combustion: no air should be supplied but through the grate; and the quantity of heat will be greatest when the air which enters is not more than sufficient for the combustion; an excess only serving to cool that which the fire had heated. The products of combustion should escape at a point not higher than the level of the grate, so that the heated matter before escaping may impart its heat to the vessel. In the common spirit-still the bottom is circular, and the exterior surface presented to the fire is concave. The fire is placed in the middle of the circle, as in the furnace of Fig. 720: the flame and heated vapour first rise up against the middle of the concave bottom, then move towards the periphery of the circle, and descend as low as the level of the grate, and enter the flue through a narrow neck, which extends through the whole periphery of the circle, and which opens into the flue all round. This narrow aperture prevents the rapid escape of the heated vapour, and allows it to be expended on the vessel.

The process of distillation is exceedingly important in a manufacturing point of view, the business of the distiller being to prepare the enormous quantities of ardent spirits which are consumed in this country and exported. The processes of the distiller preparatory to the act of distillation resemble in many respects those of the brewer. [See BEER.] He prepares a saccharine solution, or wort, and sets it fermenting by the aid of yeast; but instead of allowing the alcohol thus formed to remain in the liquor, as in the case of malt liquors, he separates it by distillation. In all the varieties of ardent spirits, alcohol, formed by the fermentation of sugar, is the intoxicating principle: the aroma or peculiar flavour which distinguishes one spirit from another seems to be due to the presence of an essential oil derived from the substance employed to furnish the saccharine solution. Thus the sugar-cane yields an oil which imparts the peculiar flavour to rum, and rum is obtained from the refuse of cane-sugar in the West Indies. The grape yields an oil which flavours brandy, and brandy is obtained by distilling wine: it is made in large quantities in France, Spain, and other wine countries. Gin, whiskey, &c., are obtained from malt or from the raw grain; the starch, which forms so large a portion of barley, being converted by the action of warm water into sugar, and this into alcohol. Milk contains a saccharine substance, known as *sugar of milk*, capable of forming alcohol by fermentation: the Tartars manufacture from mare's milk an ardent spirit named *koumiss*. Arrack is prepared from the juice of the coco-nut. [See Coco.]

The manufacture of ardent spirit, as conducted in this country, from grain, as in the preparation of whiskey,[1] comprises four principal processes: viz. 1, mashing; 2, cooling; 3, fermenting, and 4, distilling. The grain used is barley, only a portion of which is malted, in consequence of the duty on malt.

1. *Mashing.*—The barley is ground to a fine meal, and the malt is crushed between rollers.[2] Dr. Thomson gives an example from the Scotch distillers, (who have long conducted this branch of manufacture with great skill and success,) in which the proportions are 40 bushels of barley and 20 of malt The mash-tun is of cast-iron, and the water, measuring 700 or 800 wine gallons, is let in at the temperature of 150°. The mashing is continued from 2 to 4 hours, either by manual labour or machinery; the longer time being required if the proportion of raw grain prevails. To keep up the heat, about 500 gallons of water are

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[1] The word *whiskey* is said to be derived from the Irish, *usquebaugh*, which is identical with *eau de vie* or water of life.

[2] Dr. George Wilson, Professor of Chemistry at Edinburgh, informs the Editor that at the Sunbury Distillery, situated about a mile to the north west of Edinburgh, which he has visited on more than one occasion, "the grain employed is in greater part barley, which is ground pretty finely in a mill. To this a certain portion of oats is always added. They are not ground to powder, but only crushed, as the distillers call it, *rolled*, and by their presence they prevent the barley meal from clogging and caking into a mass. A small quantity of malt is added, sufficient to saccharify the starch of the barley and oats, and the fermentation is conducted in the ordinary way.

admitted at intervals, at temperatures varying from 190° to 205°. The mashing being completed, the whole is left for about 2 hours for *infusion*, as the distillers term it. During this time the grains sink, leaving the liquid but muddy wort above. A considerable portion of starch remains unaltered; but the wort gradually increases in sweetness from the beginning to the close of the operation. The wort is drawn off, not as in making beer, at the bottom, because it will not pass through the sediment of barley meal: it is drawn off from the top by a tube pierced full of holes, and rising at one corner of the mash-tun as high as the surface of that vessel. The quantity of wort does not exceed one-third of the water employed; the 1,200 gallons yielding only 400 gallons of wort. To prevent the loss of the remaining two-thirds of the wort, about 500 gallons of water at 190° are let in, and the whole, being well mixed, is left for an hour and a half to *infuse*, and it is then drawn off. The grains, having been deprived of the greater portion of their starch, now part more freely with the water; and in order to carry off everything soluble, about 800 gallons of boiling water are let in upon the grains: the whole is stirred up during 20 minutes, and left for infusion about 30 or 40 minutes. The weak wort which is drawn off is used for mixing with the meal and malt in the next brewing, or, being boiled down to the requisite strength, it is mixed with the first and second worts in the fermenting vessel. Some distillers even make a fourth mash with boiling water, and use the wort instead of pure water in the next day's brewing.

It is important that the distiller should be able to regulate the strength of his worts with precision, as the duty is regulated thereby. The quantity of spirit from 100 gallons of fermented wort is required by law to be 14 gallons: at any rate, the Scotch distillers pay that duty, whether they produce it or not. According to Dr. Thomson, 14 gallons of spirit of the specific gravity 0.90917 from 100 gallons of wort requires the original strength of the wort to be at least 70½lbs. per barrel. With the above quantities of grain, malt, and water, the first worts will be of the strength of about 73lbs. per barrel; the second worts 50lbs. per barrel, and the two, when mixed, 62lbs. per barrel.

The distiller has been for a long period so much fettered by excise regulations as to have had no opportunity of varying and improving his manufacture. The illicit distiller, unimpeded by the restraints of law, has been able to produce a better article, by using malt without any admixture of raw grain: it is also said that the superiority was partly due to the slow mode of distillation adopted by the smuggler. This superiority, perhaps further recommended by its greater cheapness, would be sure to be appreciated among a whiskey-drinking people: the illicit distiller would therefore be favoured and protected, and thus the morals of the people, the revenue, and the regular manufacturer, would all suffer in consequence of in[illegible] on the part of the government. Of late years, however, the distillers have been allowed to distil from malt at nearly the same rate as they formerly did from raw grain, and hence the high reputation of smuggled whiskey has declined, and with it the occupation of the smuggler. The restrictions under which the distillers were placed were said to be necessary in order to ensure the payment of the duty on the spirits actually distilled. But, as Dr. Thomson suggests, the duty might be levied with as much accuracy, though all restrictions on the strength of the wort were removed. "From a number of experiments, conducted on a large scale, we conclude that the fermentation, however successful, is capable of decomposing only four-fifths of the whole saccharine matter contained in the wort. Further, we find that, for every pound of saccharine matter decomposed by the fermentation, there is formed half a pound of alcohol, of the sp. gr. 0.825. Now, every gallon of spirits of the sp. gr. 0.90917, or 1 to 10 over proof, contains 1.6lbs. of alcohol of the sp. gr. 0.825. To form a gallon of spirits, then, of the sp. gr. 0.90917, there is required the decomposition of 9.2lbs. of saccharine matter. But as only four-fifths of the saccharine matter present are decomposed, we must increase 9.2 by a fifth, which will raise it to 11½lbs The rule, therefore, for levying the duty on the distillers would be this:—Ascertain by the saccharometer[1] the strength of the wort, or the number of pounds avoirdupois of saccharine matter which it contains, and for every 11½ of these pounds charge the duty upon one gallon of spirits. This would be no hardship upon the distiller. He would find that the flavour, and consequently the value of his spirits, increases as he diminishes the strength of his wort, and that the produce of spirits from the same quantity of grain increases also as he diminishes the strength of his wort."[2]

2. *Cooling.*—As wort from raw grain tends to acidity sooner than wort from malt, the distiller cools his worts as quickly as possible. They are removed from the underback to the coolers, consisting of shallow wooden vessels, in the upper part of the building: the depth of the sheet of wort may be 1, 2, or 3 inches, according to circumstances. Another method of cooling is by passing the wort through pipes immersed in a stream of cold running water. There is no evaporation in this method, as there is in the former, and consequently the strength remains the same after cooling as before. This is of some disadvantage to the distiller, as the duty is levied on the bulk and not on the strength of his worts. During the cooling there is a considerable deposit of flocky matter, consisting chiefly of starch: this is swept into the fermenting tun, and is supposed to assist the fermentation. Winter is the usual season for the operations of the distiller, as it is difficult in warm weather to keep the fermenting room sufficiently cool. The worts are let down at about 70°, and the second worts at 60° or 65°.

3. The process of *fermentation* is the most important part of the manufacture, as on it the profit or the loss

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(1) See Beer, *ante*, p. 117, Fig. 111.

(2) Encyclopædia Britannica; art. *Distillation*.

of the manufacturer chiefly depends. The yeast, which is supplied by the porter and ale brewers, must be of the best quality. For the quantity of wort already indicated, about 27 gallons of good yeast are required, or 36 gallons if the yeast be of inferior quality. A portion only is first mixed with the wort, other portions being added on the second, third, fourth, and even on the sixth days. Some distillers add 9 gallons every day for 4 days. The fermentation may last 9, 10, 11, 12, or even 13 days. During the first 5 days the fermenting tuns are left open at the top, or are only partially covered; but on the sixth day they are shut up for the purpose of confining the carbonic acid gas, which in escaping carries off a portion of alcohol, and thus occasions loss. It generally happens, however, that the fermentation is nearly over before the tuns are shut, so that the loss of alcohol by the escape of carbonic acid has already occurred. The presence of the carbonic acid is also supposed to promote fermentation, and by preventing its ready escape the attenuation of the wort is supposed to be greater than it otherwise would be. This may be true, because it is known that carbonic acid may be substituted for yeast as a ferment. The distiller does not collect any yeast from his worts, but beats it all into the liquor; he supposes that by collecting it the fermentation would be less complete, and the alcoholic product diminished. During the fermentation the temperature of the wort rises considerably; often as much as 20° or 25°, so that if let down at 57° its temperature may rise to 78° or 82° about the fourth or fifth day. The time when this maximum is attained is, however, uncertain, and depends to a great extent on the quality of the yeast employed; and it is the uncertain character of the yeast which makes the difficult business of the distiller still more difficult. As the fermentation proceeds, the specific gravity of the wort diminishes, owing to the decomposition of the sugar and its conversion into alcohol and carbonic acid. In all cases of fermentation, in a Scotch distillery at least, one-fifth of the whole of the saccharine matter escapes decomposition, in consequence of the anti-fermenting power of the alcohol evolved. Hence it is more profitable for the distiller to operate with weak worts than with strong ones, for the weaker the original wort, the less will be the quantity of the saccharine matter which escapes decomposition. When the heat is at its maximum nine-tenths of the whole attenuation has been completed. The object of the distiller is to render his *wash*, or fermented wort, as light as water, and he will be able to do so unless his yeast be of bad quality.

When yeast cannot be readily procured, a substitute called *bub* is employed. It is prepared by thoroughly mixing together a quantity of meal or flour with a little yeast in a quantity of warm worts and water: the whole being closely covered up, a violent fermentation almost immediately ensues, and in that state it is added to the worts. Should the fermentation be found to lag, some yeast is added; but for revenue purposes the whole quantity of bub and yeast is not allowed to be more than five per cent. on the quantity of worts previously collected. This allowance is generally found to be more than sufficient.

Dr. George Wilson informs the Editor that at the Sunbury Distillery the cost of yeast is 50*l* per week. He says that the Scotch whiskey distillers trust to the care bestowed by the ale and porter brewers, that the yeast is sufficiently often varied and otherwise in good condition; the brewers exchanging yeast with each other at intervals,—a practice which is necessary to prevent the yeast from deteriorating. The brewers mingle the yeasts of different breweries together until they produce a liquid of a certain thickness and strength, of which they judge by an empirical rule. They seem to be indifferent as to the source of the yeast, so far as beer, ale, or porter are concerned; but they aim at securing a standard strength, by mixing the thin and the thick, the active and the sluggish.

A practical writer thus describes the phenomena of fermentation:—"Soon after the yeast or bub has been added to the worts, fermentation commences: its first effects are indicated round the sides of the back by the appearance of a scummy-looking matter on the surface of the worts, and the emission of small bubbles which contain carbonic acid gas. The temperature increases as fermentation advances. Its progress is rather slow at first, but gradually increases, and after some time proceeds with great rapidity. Large bubbles of carbonic acid gas escaping set the whole in motion, as if in a state of violent ebullition; a large quantity of froth collects on the surface of the liquor (which is now called *wash*), which often accumulates with such rapidity that several men are required to beat it down with oars, to prevent its spilling over the top; indeed, on some occasions, the beating on the top has been found ineffectual, and the distiller forced to pump a portion of the wash up to the coolers, to lower its temperature, and then return it, after which the process proceeded at a moderate rate; and in all cases, towards its close, the rate of fermentation gradually diminishes, and the temperature decreases, till at last the wash acquires the temperature of the tun-room, and remains quiescent."[1]

Dr. George Wilson, in a letter to the Editor, thus notices the fermenting-tuns of the Sunbury Distillery: "I thought of Priestley as I stood at the small doorway of one of the immense vats, from which the mixed vapour of alcohol and carbonic acid was issuing, extinguishing candles held near it, and falling with a binding anæsthetic weight on the breathing organs of all respiratory animals near it. Professor Simpson tells me that he thinks the intoxicating power of champagne is owing to the vaporization of alcohol along with carbonic acid. I always thought the theory a true one, but I realized its truth to-day. A single whiff of the vapour, gushing forth in sufficient volume to *blow* upon the face, was enough to make a friend and myself spring back with our hands on our faces. We did not try a second draught."

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(1) Thomson's "Records of General Science," vol. ii.

The wash-backs or fermenting tuns are of large size, to prevent the heat from being dissipated; and they are only partly filled, to prevent the wort from frothing over when it is in full fermentation. Some distillers, however, fill the tuns almost to the top, and close the mouth tightly with a lid, from which a tube passes to an open vessel placed above the tun, so that when the liquor swells by fermentation, it passes up the tube into an open vessel, and runs down again when the fermentation subsides. The fermenting tuns are sometimes made in the form of a cone standing on its larger base, and either round or oval, but sometimes they are square: some are of wood, others of iron. Iron, being a better conductor of heat than wood, has this advantage, that either hot or cold water may be applied in an outside case, to regulate the temperature of the wash contained in the back.

4. As soon as the fermentation is over, the wash is distilled. The stills formerly used were very large and deep, and a whole week was required to complete the process in one still. About the year 1787, however, an alteration was made in the method of levying the duty, with the view, as it was supposed, of making it more difficult for the distillers to evade it. The duty was, accordingly, levied on the distillers by a licence paid at the commencement of the season on every still in use, according to its capacity. The quantity of spirits which a still of known dimensions could produce in a year was calculated, and the sum paid for the licence was laid on it accordingly. This plan saved the excise officers much trouble, but the distillers took advantage of it with very remarkable results. The very next year after the plan came into operation, a firm in Leith diminished the height and increased the diameter of the bottom of their stills, so that by exposing a much larger surface to the action of the fire they could distil off the contents in a few hours instead of once a-week. In this way, by producing a large quantity of spirits from a very small still, they paid a much smaller amount of duty than their neighbours. A discovery so important in its pecuniary results was not likely to remain a secret very long. After some months the practice was adopted by other distillers, and it soon became general in Scotland. Parliament met the case by increasing the licence duty; this was done several times, but after each increase, the manufacturers worked their stills quicker and harder than ever, so that they, and not the revenue, were the gainers. In 1799 a Committee of the House of Commons was appointed to investigate the subject, and in consequence of their report the licence was laid on the distiller on the supposition that he could discharge his still every 8 minutes during the whole season that the manufactory was in operation. These 8 minutes were, however, considerably shortened by the distiller, but the saving in time was accompanied by such an enormous waste of fuel, as to render the additional profit doubtful. In 1815, the last year of the licence duty, a still of 80 gallons could be completely distilled off, emptied, and ready for a new operation in 3½ minutes, and in some cases 3 minutes; and a still of 40 gallons in 2½ minutes. At this time, however, a change was made in the excise laws; the licence duty was abolished, and the whole duty was levied as in England on the wash and the spirit produced. After this the slow process of distillation was again adopted; not so slow as before, for the quick method left some of its traces behind, and the new stills were, accordingly, made to resemble the quick ones in the large diameter of their bottoms, and their comparative shortness compared with the stills used in England.

Various forms of distillatory apparatus are used in Scotland, the principle of which will be described presently. We will first speak of the operations as conducted by the common still, before we refer to more complicated forms of apparatus.

When the wash has been put into the still the top is fixed down and heat applied. As spirit is more volatile than water, it passes over first in the form of vapour, and is condensed into a liquid in passing through the worm. The first portions are very strong, but the strength diminishes as the process proceeds; for the same heat which drives over the vapour of alcohol also drives over some vapour of water, and the two being condensed together mingle in the liquid state. At the beginning of the process much more alcoholic than aqueous vapour passes over, and towards the end of the process much more aqueous than alcoholic. When the liquid that comes over is as heavy as water, or nearly so, the process is stopped. The strength is tried every now and then by means of a small hydrometer, and when a certain mark on the instrument coincides with the surface of the liquor, a cock at the bottom of the still is opened, and the spirit wash is let off. It is a muddy, brown liquor, still containing undecomposed saccharine matter: it is used as food for cattle; they are very fond of it, and fatten quickly upon it.

At the commencement of the operation the still is apt to boil over. To prevent this it is usual to throw a bit of soap into the wash: this is partly decomposed, and the oily matter spreads on the surface and forms a thin coat, which breaks the large bubbles when they reach it, and thus prevents the wash from swelling beyond the proper bulk. Spirits may sometimes be met with having the nauseous taste of soap: this arises from morsels thereof having been accidentally forced into the worm, and afterwards dissolved by the spirit.

The weak spirit obtained by the first distillation is called *low wines* in Scotland. Its specific gravity at 60 is about 0.978; it contains about one-fifth alcohol of the sp. gr. 0.825, the remaining four-fifths being water. The *low wines* are distilled a second time by a process called *doubling;* the first portion that comes over is a milky liquid; this is called *foreshot;* it is loaded with oil, and has a disagreeable taste; it is returned back to the low wines and distilled again. When the spirit begins to run transparent from the end of the worm, it is allowed to flow into a receiver prepared for the purpose. When the specific gravity has reached a certain point, as determined by the hydrometer, the spirits are no longer allowed to flow into the receiver, but into another vessel, and the distillation is continued until the sp. gr. of water is nearly attained. This third portion is called *faints*: it is mixed with the low wines and distilled again. The distillation of the low wines is continued till the whole of the alcohol is brought to that degree of strength which is adapted to the market. The strength at which the duty is levied on them is 1 to 10 above hydrometer proof; this corresponds to the sp. gr. 0·9017. The distillers are not allowed to send out spirits of greater strength than this, or of a strength under 1 in 6 below proof, or of sp. gr. 0·9385.

The Scotch distillers use the best English barley for malting, for this when malted yields more spirits than raw grain: but when raw grain is used, bere answers the purpose as well as barley, and is more economical.

It has already been stated, that in addition to the alcohol which passes over with greater facility than water, there are other volatile matters furnished by the vegetable substance from which the fermented liquor is procured. These are essential oils, which vary with the kind of fermented liquor employed. When they are from wine or from the wash made from sugar, their flavour and aroma are agreeable: the oils furnished by malt and grain are, however, very disagreeable, and when the old form of still is used, it is the business of the *rectifier* to remove them.

The rectifier procures his spirit from the distiller in the state of what is called *raw spirit*, that contains all the volatile impurities which pass over in the first process. The rectifier purifies his spirit by a method of his own, but his distilling apparatus by the old plan is in every respect similar to that used by the distiller; only he applies his heat with greater caution. It does not always happen that the rectifier removes the offensive aroma from the raw spirit; he may substitute another which overpowers the original: this is generally done in the different kinds of gin and other compound cordials. In some cases when the spirit is very weak and the essential oils are abundant, the water exerts a greater attraction for the alcohol than the alcohol does for the oils: a portion of the oil thus becomes free, and gives the liquid a milky appearance. The oils are in such case separated by adding alkalies, which forming soapy compounds therewith do not pass over with the spirit at the moderate heat employed in the rectification. By the addition of acids the oils are converted into resinous substances, by which they also become less volatile.

Whiskey and gin are by far the most important varieties of spirits produced by British manufacture. The Dutch are celebrated for the manufacture of gin, Geneva, or Hollands. According to Dr. Thomson, the following is the process:—112lbs. of barley-malt and 228lbs. of rye-meal, are mashed with 460 gallons of water at 162°. After infusing a sufficient time, cold water is added until the gravity of the wort is reduced to 45lbs. per barrel. The whole is let into a fermenting back at [illegible] yeast is added; the temperature rises to 90°, and the fermentation is over in [illegible]. The wash is attenuated until the gravity is about 12 or 15 lbs. per barrel. Both the wash and grains are then put into the still; the low wines are distilled off; these are redistilled, and the product is rectified. A few juniper berries and some hops are used to communicate a peculiar flavour to the spirit.

Instead of referring to the article STILL for a detailed description of that most important apparatus, it will be desirable to introduce what we have to say on the subject in this place.

We have seen that when a mixed liquid, consisting of two ingredients of different degrees of volatility, is exposed to the action of heat and made to boil, the more volatile ingredient passes over first, and can then be separated more or less perfectly from the less volatile portion. If the difference between the boiling points of the two liquids be not very great, the separation is imperfect, as, for example, in a mixture of strong alcohol and water, the boiling point of the alcohol being about 176°, and that of the water 212°. When this mixture begins to boil, the vapour of alcohol which comes over brings with it a portion of the vapour of water, so that the distilled liquid is not alcohol, but a mixture of alcohol and water. At the commencement of the process, the boiling point of the mixture is something intermediate between the boiling points of the two liquids when separate, *viz.* 176° and 212°; it is probably about 190°, but as the alcohol distils over, the temperature gradually rises until all the alcohol has distilled over, and then it reaches 212°. Hence it will readily be seen that the first portions which pass over will contain most alcohol, and the last portions most water. As the hot vapours pass into the worm (Fig. 711), it gradually cools and condenses: the water which surrounds the worm being hottest at the top, gradually cooling in the middle, and becoming cold at the bottom, the differences of temperature in the worm varying from the temperature of the boiling liquid to that of the atmosphere. Now, as the alcohol and the water differ in volatility, they differ also in condensability: as the liquids are converted into vapours at different temperatures, so the vapours are condensed into liquids at different temperatures; and as these different temperatures exist at different parts of the worm, it follows that the vapour of alcohol is condensed at one part of the worm, and the vapour of water at another part. The vapour of water begins to condense as soon as it enters the worm, because it is immediately reduced to a lower temperature than 212°, which is necessary to its vapourous state. The vapour of alcohol, however, can exist at a much lower temperature than that of water, so that in those parts of the worm where the vapour of water is being condensed, the vapour of alcohol retains its elastic state, and passes on to that lower part of the worm where, the temperature being below 176°, it necessarily becomes condensed. In the ordinary construction of the worm, however, the water condensed in the upper part of the tube flows down and mixes with the alcohol condensed in the lower part of the tube, and the separation which has been effected in so refined and delicate a manner by a natural process, and which it is one of the great objects of the distiller to accomplish, is defeated in consequence of the defective construction of the still. To remedy this, the liquid condensed by the worm, was distilled by the rectifier, as already stated, a second, a third, and even a fourth time, the object being to separate the water which actually had been separated by the worm in the first process; and thus time, labour, fuel, and apparatus were engaged in 4 operations when, by a more scientific arrangement, one operation might have sufficed. Various attempts had been made to remedy the defect, without success; some distillers tried to shorten the time in which a given quantity of spirit of the usual strength could be obtained; others attempted to shorten the time, and also to obtain a stronger spirit; a third set of improvers endeavoured to economise the heat; a fourth set, to render the apparatus self-acting, and constant in its operation. With respect to the shortening of the time, the Scotch distillers, as already noticed, produced the most extraordinary effects. Taking advantage of the method by which the duty was levied on the capacity of the still, instead of on the quantity of spirit produced, they endeavoured to improve their stills so as to make them furnish a larger quantity of spirit. The distillers found that the more shallow the still, the broader the bottom, and the larger the furnace and supply of fuel, the more rapid was the distillation. After various forms of still had been tried, one was invented by Mr. Millar of a capacity equal to 16 gallons of wash, or 24 gallons of singlings, and so judicious were the arrangements, that the still might be charged, run off, and discharged nearly 22 times in an hour. In this still steam was allowed to pass off at as many points in the shoulder of the still as possible; a fly kept in constant motion in the head of the still broke the froth, and prevented the still from running foul; an agitator kept the boiling wash in constant motion, so as to prevent the deposition of any sediment, and if any sediment formed it was prevented from being burnt by the fierce heat by a piece of machinery which constantly scraped it off from the bottom.

An adaptation of this still by Sir Anthony Perrier, of Cork, is shown in Fig. 717, in which the liquid to be distilled is made to flow gradually and continuously over the heated surface of the boiler, while it continues to part with its alcohol. The bottom of the boiler is divided by concentric partitions, which stand up sufficiently high to prevent the liquor from boiling over: these partitions have openings from one to another at opposite sides, so as to make the course a sort of labyrinth. *a* is a reservoir of liquor prepared for the operation, *b* a pipe descending therefrom, and conducting the liquor into the boiler at *c*, which is the commencement of the labyrinth, in flowing through which it progressively traverses the whole surface of the bottom, so that the full effect of the fire is exerted upon small portions of the liquid, which causes the evaporation to proceed with great rapidity. The spent liquor passes off by the discharge-pipe *d*. A deposit is prevented from forming and burning by means of the chains suspended from the bar *e e*, which is supported by a centre shaft set in motion by means of a toothed wheel and pinion. These chains hang in loops, and fall into the spaces between the partitions, to sweep the bottom of the still as the shaft revolves.

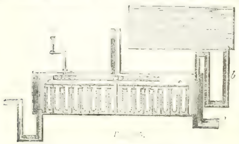

Fig. 717.

In this still the great defect already noticed was not remedied, for the vapour of water and of alcohol condensed at different parts of the worm mingled together at the bottom. Mr. Coffey, a distiller of Dublin, seems to have been the first, in this country at least, to remedy this defect, by inserting in the first and second rounds of the worm two pipes, which, passing down, entered the boiler of the still, so that the vapour of water, being condensed in these first two rounds of the worm, passed down these pipes into the boiler, while the vapour of alcohol, retaining its elastic form, passed on beyond the first two rounds, and condensing in the lower and cooler part of the worm could be separately collected.

The principle of this ingenious still was not new at the time of Mr. Coffey's invention, for some of the early chemists, such as Jean Baptista Porta, Lefevre, and Glauber, had adopted it. The merit of Mr. Coffey's still was in the simplicity with which the principle was applied. In the old forms of still a straight, spiral, or zigzag tube proceeded from the head of the boiler, and at the upper end of the tube was affixed another head, from the side of which proceeded a pipe for discharging the distilled liquor. The watery vapours condensed in the upright tube which proceeded from the head of the boiler, and the alcoholic vapours passing through it were condensed in the upper head, or capital, which in some cases was surrounded by cold water.

It is necessary to refer more particularly to Glauber's apparatus, on account of the important influence which it had on the art of distillation at the commencement of the present century. Glauber died in 1668, but his apparatus, as modified by Woulfe, (who died in 1805,) is much better known by the name of the latter. It consists of a series of close vessels, *a b*, *c*, Fig. 717, placed side by side, connected by tubes, 1, 2, 3, fitting in tight joints, and originating from the top of those which precede in the series, descend to the bottom of those which succeed. Now, the object for which this apparatus is chiefly used in scientific chemistry is for the purpose of impregnating

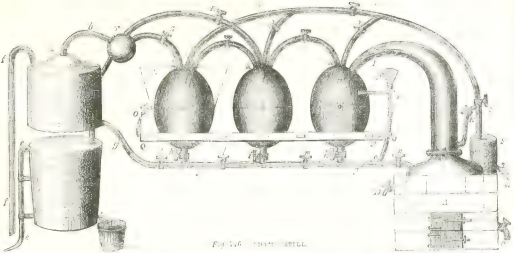

Fig. 716. ADAM'S STILL.

liquids with gases, and as such we shall describe it. Suppose it were required to impregnate a certain quantity of water with muriatic acid gas. The gas is supposed to be delivered into the bottle, *a*, by the tube 1; it is immediately dissolved by the water, but as from the continual additions of gas the liquid becomes saturated, a portion of the gas passes into the upper part of the bottle, and propelling the air before it enters the bottle *b* by the tube 2. Here it acts exactly as in the bottle *a*, and having saturated the water therein, it passes in a similar manner on to a third bottle, *c*, and from that to wherever the tube 4 may lead. The tube *d* is called a *safety tube*, and its use is to admit air into the bottles when the internal pressure becomes less than that of the atmosphere. If, for example, the supply of gas into the bottles *a* and *b* were stopped while solution was still going on; as the water dissolved the gas above it, the atmospheric pressure would force the fluid from the bottle *c* up the third tube into the bottle *b*, and from thence up the second tube into the bottle *a*. This is prevented by the safety tube, which passes through a tight joint into the bottle, and has its lower extremity immersed in the liquid to the depth of half an inch or more. When the absorption of the gas takes place, air passes down the tube, enters the bottle, and prevents the liquid from the other bottles from being forced up the tube. If, on the contrary, the gas accumulates in one of the bottles faster than it is absorbed, its pressure on the surface of the liquid forces a column thereof up the safety tube.

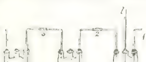

Fig. 717. WOULFE'S APPARATUS.

In the first year of the present century, a Frenchman named Edouard Adam, who is described as "an obscure person, unacquainted with science, and ignorant of the art he intended to improve," happening to be present at a chemical lecture at Montpelier while a Woulfe's apparatus was being exhibited and explained, conceived the happy idea of applying such an apparatus to the distillation of brandy from wine. He immediately set to work and constructed a small apparatus, which after repeated alterations was found to answer the purpose for which it was intended. In 1801 he obtained a *brevet* or patent for his invention for 10 years, and from this time the art of distillation became completely changed, not only in the wine countries of France where brandy is manufactured, but also in other countries where ardent spirits are made. The forms of still are almost innumerable, but the principles which regulated the construction of Adam's still are observed in all, modified only according to the special purpose intended to be answered.

Fig. 716, is a view of Adam's still, which we will describe somewhat minutely. A number of egg-shaped vessels H H H, made of copper, are supported on their small ends by the framing P Q, the upper or large end of each being perforated, we will suppose with two holes, for the reception of copper tubes which connect the vessels together. From the top of the first egg at K proceeds a tube M H, which plunges to the bottom of the second, and terminates in a perforated rose like that of a watering-pot. From the top of the second egg proceeds another tube, which passes to the bottom of the third egg, and so on to the end. The tubes fitting steam-tight in the holes, it is evident that if the eggs be half filled with liquid, air blown through the first egg will bubble through all the eggs and escape at the last. But suppose that instead of air, the vapour from a fermented liquor, such as wine, be passed through the eggs half filled with wine, and that wine is also contained in a still B, to two-thirds of its height as regulated by the cock D, and that this still is heated by a furnace A: the vapour of alcohol mixed with watery vapour will be discharged through the tube I, into the first egg, where both vapours will be condensed and absorbed. The wine in this first egg thus becomes richer in alcohol than it was, and also becomes heated by the condensed vapours. This wine cannot, however, become as much heated as the wine in the boiler, because containing more alcohol it boils at a lower temperature. The consequence of its boiling at a lower temperature is that alcoholic vapours containing less water will be discharged into the second egg, the wine of which becomes in its turn richer in alcohol than the first, and will boil at a still lower temperature. In like manner the alcoholic vapours from the second egg will enrich the wine of the third egg, and making it strongest of all, it will boil at a still lower temperature, and the alcoholic vapour discharged from it may be passed through a worm U, and condensed. If a weaker spirit is required, the third egg may be dispensed with; this is cut off from the rest by closing the stop-cock M′ and opening the stop-cock R, which connects the second egg with the worm U. If a stronger spirit be desired, a fourth egg may be added, for in every egg alcohol is separated from water, the greater part of which is left behind. According to the inventor, the greater the number of eggs, the better the rectification would be carried on. The last egg is furnished with a cooler X surrounding the upper part, and containing water which as it became heated was let out at O. The worm, however, in which the spirit is finally condensed is not cooled by the presence of cold water in the worm tub, but by cold wine, which becoming heated by the worm is thus prepared for the boiler A; for when the alcohol has been separated from the wine in the boiler and the eggs, the watery residuum is let off by a cock C, and the hot wine from the refrigeratory let in by a tube *gg*. The refrigeratory is then refilled with cold wine. The worm tub containing the cold wine is entirely closed; but at the top is a dome *a*, whence proceeds the pipe *b*, which collects any alcoholic vapours that may be formed in consequence of the heating of the wine in U, and pours them into the globe T, in which the vapours from the eggs are collected before passing into the worm. The large tub V encloses a second worm filled with water, kept cold by constantly drawing off from the top where it is hottest by means of the pipe *e*.

The strength of the spirit in each egg can be proved by means of the tube X X, which proceeds from the last egg and communicates with the small worm F. From the head of the still and also from each egg a tube opens into the tube X, and as each of these branch tubes is furnished with a stop-cock, the vapour from the still or from any one of the eggs can be condensed in the worm F, and the spirit drawn off at G, while all the other parts remain closed.

The wines destined for distillation are kept in a storehouse, and are pumped up into the tub U along the conducting pipe *ff*, which proceeds nearly to the bottom of the tub. The pipe *gg* communicates with the still and the eggs: *hik*, are stop-cocks for continuing or interrupting the communication between each egg and the still for the purpose of discharging it, or with the condensing vessel for the purpose of filling it. The still and the eggs can also be charged with brandy or with feints by means of the pipe *oo* which opens into *g*.

In setting this still to work the stop-cocks ***hik*** are closed, and *lmn* are opened, when the wine from U flows into the still, fresh wine being meanwhile pumped up until the still is two-thirds full, as indicated by wine flowing out of D. D is then closed, as also *n*: *k* is opened, and wine flows up into the first egg until it is half full, when it begins to flow out at a tube placed at L: this pipe is then closed, as also the stop-cocks *k* and *m*: *i* is then opened and half filled in like manner, as are also the other eggs except that one which acts as a condenser, which in Fig. 716, is the third egg. No liquor is put into this; but the cooler being filled with water, all the lower cocks are closed and the upper ones opened to afford a free passage to the vapours. The fire is then urged, and the distillation proceeds as already described, the alcoholic vapours traversing the three eggs, condensing in the upper worm, and, being completely cooled in the lower worm, the ardent spirit passes out at the stop-cock, and is received in a proper vessel, which is sometimes a hogshead. In order that the alcohol may not evaporate in passing from the worm into the hogshead, and at the same time to allow the stream to be seen, a glass pipe is attached to the extremity of the worm. The products of the still are received until the liquor is found to diminish in strength: the first hogshead is then removed and replaced with another, to receive what are called the *repasses* or feints, which are again passed through the still. The point at which the operation requires to be arrested is ascertained by condensing some of the vapour in the small worm F, and opening the stop-cock G, some of the spirit is received in a glass: fire is applied to this spirit, and if it does not burn, the process is stopped. This loose and inaccurate method has been of late years superseded by the hydrometer. When no spirit is formed, the fire is extinguished, the residuum is let out, and the still is fresh charged as already described.[1]

Great and decided as was the improvement effected in the art of distillation by Adam's still, yet it was evidently liable to the defect of not being continuous: for as soon as one charge was elaborated, the fire had to be withdrawn, the residue let out, and the apparatus charged afresh, the fire relighted, and so on. This defect was partially remedied in 1805, by M. Isaac Bérard, whose condensing apparatus offered the further advantage of being capable of being adjusted to any existing form of still. The success of this apparatus alarmed M. Adam, who took legal proceedings against Bérard for infringement of patent, but it was clearly proved by the eminent Chaptal, that although the principle of the two inventions was the same, yet that principle was by no means new, and was applied in a very different manner in the two inventions. In 1808, M. Blumenthal combined the two inventions in a still, in which wine continually flowed in at one part of the apparatus and escaped at another, entirely deprived of its alcohol. Some years later M. Derosne became the proprietor of this apparatus, and further improved it. We will first state the principle of this contrivance, and then describe the apparatus by which it is carried out. A copper boiler is set in masonry with a fire beneath: the mouth of the boiler is fitted with a tall copper cylinder standing perpendicularly over the boiler and fitting closely. About half way up the height of this cylinder and in its axis, a slender tube enters it and discharges a continual but small stream of the wine or wash to be distilled. The wine is prevented from falling down directly into the boiler beneath by means of a number of diaphragms, through which the wine percolates in streams like rain, whereby it presents a large extent of surface to the vapour which passes it in a different direction. In some cases the ascending vapours have to force their way at each diaphragm through a thin stratum of liquid, and they thus undergo a certain amount of pressure. The wine when it enters the cylinder is almost boiling, and while it falls in small showers through the pierced shelves, a copious issue of watery vapour ascends from the boiling copper below. The watery vapour at the temperature of boiling comes in contact with the streams of wine almost boiling: the latter therefore receive heat from the former, and by so doing there is a change of state; the watery vapour, losing heat, falls back as water; and the wine acquiring heat, boils, and its alcohol in a state of vapour rises higher up in the cylinder, where meeting with wine it is absorbed, and a wine richer in alcohol is produced. This more alcoholic wine readily parts with its alcohol in the form of vapour, by the action of heat continually carried up the cylinder. This vapour of alcohol ascending higher meets with more wine, is absorbed, and again set free in larger quantity. At length the portion of wine high up in the cylinder becomes highly charged with alcohol, and the alcoholic vapours meeting with no more wine, pass on to a worm, where they are condensed into very strong spirit. The worm tub is filled with wine, which in cooling the worm becomes heated itself, and this heated wine flows through the slender tube into the cylinder, where it is distilled as already explained. As this worm is never perfectly cold, the alcoholic vapour which escapes condensation is passed through a second worm, also surrounded by wine, which condenses it completely.

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[1] "Essai sur l'Art de la Distillation," par L. S. Lenormand, Paris, 1811. The reader who wishes to study the art of distillation in greater detail is referred to one of the cheap and useful Manuels Roret, entitled, "Nouveau Manuel Complet du Distillateur et du Liquoriste," par Lebeaud and Fontenelle. Paris, 1843.

Should the watery vapour which ascends from the boiler into the cylinder, and becoming condensed falls back into the boiler, carry any alcohol with it, the latter is again volatilized; so that the boiler contains nothing but water derived from the wine; for although the boiler had been filled with wine, it soon becomes water by parting with its alcohol. As fast as the boiler fills with water, it is emptied by a cock placed in the bottom. Two boilers are more efficient than one, and when arranged so that a tube proceeding from the head of one plunges to the bottom of the other, they act like two of the eggs in Adam's still. The discharge of wine from the great reservoir is regulated by a ball-cock, and there is a constant supply of cold wine, *first*, to the two worms for the purpose of cooling them, (by which method of heating the wine fuel is economised;) *secondly*, to the distillatory column. Having parted with its alcohol, the watery portion falls into the boilers, whence it is let off entirely deprived of alcohol. The flow of wine being thus perpetual, no time is lost by an interval of discharging and charging. It must also be noticed that when the alcoholic vapours enter the first worm they are condensed; but as the weakest or most watery alcohol condenses in the first rounds of the worm, it is so contrived that this watery portion shall run back by small tubes into the cylinder, where it is re-distilled. The worm at all its rounds is provided with cocks and tubes, by which the portions condensed in any part may be let back to be re-distilled, or they may be all shut, or some may be left open, so as to return the whole or any part into the cylinder. In this way, by means of these cocks, alcohol of any required degree of condensation, within certain limits, can be obtained.

The apparatus by which these complicated effects are produced is shown in Fig. 718. It consists of two boilers A A', a distillatory column B, a rectifier C, a condenser D, which also serves to heat the wine, a refrigerator E, a reservoir of wine G, which feeds a small cistern F, the supply being regulated by a ball-cock. The boiler A is filled through the pipe H, and emptied by means of the stop-cock R. The height of the liquor in the boilers is indicated by the glass tubes *xx'*. The pipe Z, proceeding from the head of A, conducts vapour to the bottom of the boiler A' and thus these two boilers act like two of the eggs in Adam's apparatus. The boiler A' is heated by the flue of the fire under A. The second boiler is filled by means of the tube H', and by the cock R' the contents of the second boiler are transferred to the first. The distillatory column B, and the rectifier C, contain a number of diaphragms, the use of which will be explained presently. The condenser D is a cylinder of copper placed horizontally; it is divided into two unequal portions by a diaphragm, at the lower part of which is an opening for allowing the two portions to communicate: the condenser contains a worm, the axis of which is identical with that of the condenser; this worm commences at M and terminates at O: each spiral of the worm has at its lower curve a small pipe, *a*, connected with a sloping pipe, which conveys the whole or only a portion of the liquid from the worm into the pipe O, or into the rectifier, according as the stop-cocks 1, 2, 3, are opened or shut. At U, V, X, the column can be opened for cleansing when required. L is a pipe which conducts hot wine from the condenser to the distillatory column. The refrigerator E is a close copper cylinder, containing a worm which originates at O, and terminates in the tap below. It is kept filled with cold wine by means of the pipe I, and when quite full, the wine rises up the pipe K, and fills the condenser D.

This apparatus is set in action by first pouring into the boiler A the liquor which is to be distilled, until the level is within 2 or 3 inches of the top of the gauge *x*. The boiler A′ is also charged until the level stands 5 or 6 inches above the cock R′. On opening the stop-cock *r* the tube I, the refrigerator F, and the condenser D, are filled with wine, the air escaping by H′, and as soon as it is seen by the elevation of the level of the liquid in the boiler A′ that wine is flowing over by the tube L, the stop-cock *r* is shut. The fire is then lighted under A, and as soon as the wine in this copper begins to boil, vapour escapes by the pipe Z, condenses in the boiler A′, and by this means, together with the assistance of the heat of the flue which passes under it, the liquor soon boils. The alcoholic vapours ascend in the column B, pass into the worm in D, where they condense, and the liquor returns for the most part into the rectifier C. When the wine in D is sufficiently heated (which is judged of by the outside being too hot for the hand to rest upon it), the stop-cocks R R′ and *r* are opened and the distillation continues. The wine conducted by the pipe I ascends into the refrigerator E, where it is gently heated; it then passes up K into D′, where it is heated still more; and then passing through the opening in the lower part of the diaphragm, it enters D″, where its temperature is raised nearly to the boiling point: it then falls by the tube L into the distillatory column B, where it undergoes considerable subdivision. Having at length reached the boiler A′, it passes through the pipe R′ into the boiler A, and from this it escapes by R, entirely deprived of its alcohol. The vapour from the boilers, which follows the same route, has been already traced.[1]

Thus it will be seen that this apparatus is continuous in its operations; the wine being furnished at one place, and, being deprived of its alcohol, escaping at another in a continued stream. "It is obvious, however, that this still does not literally afford strong alcohol from wine or wash at one distillation, as is commonly said of it; for it actually undergoes repeated distillations in the cylinder. One apparent process only is necessary, and one fire answers for all. In its operations it is continual. There is a saving of fire, superintendence, and time; there is a greater product of alcohol, and the alcohol has a purer flavour, because there are no empyreuma, as the fire is never directly applied to the wine. Indeed, the want of empyreuma has been found an objection to the still: the consumers were so dissatisfied at the want of the accustomed burnt taste, that the required flavour was obliged to be communicated by various empyreumatic substances."[2]

Derosne's apparatus was further simplified by M. Laugier, whose still is described in M. Péclet's work already referred to. We pass on to consider the application of the new stills, or rather of the principles of their construction, to the stills of this country.

The French stills for distilling brandy from wine are not adapted to the glutinous wash of grains, which would soon clog up the small pipes and channels. In introducing the principle of continuous distillation into this country, it was therefore necessary to modify the apparatus. Several such contrivances have been brought forward, among which may be mentioned that by Mr. Æneas Coffey, of Dublin, patented in 1832. It is represented in section in Fig. 720;[3] it consists of a body or oblong vessel, B B′, and two columns erected thereon, one of which, C D E F, is the *analyser*, and the other, G H I K, the *rectifier*. The whole is made of wood, lined with copper, and the wood being 5 or 6 inches thick, little or no heat is

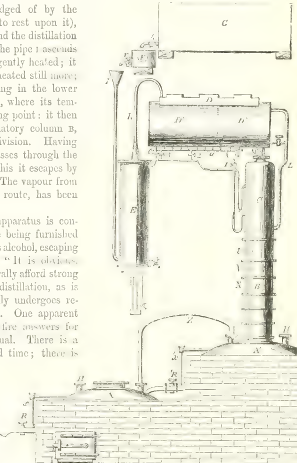

Fig. 718. FRENCH BRANDY STILL.

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[1] Péclet: "Traité de la Chaleur, considerée dans ses applications."

[2] Donovan: "Domestic Economy," vol. ii.

[3] We are indebted for this figure and description to Dr. Thomson's "Records of General Science," vol. iii.

lost by radiation. The body has a copper plate or diaphragm, *cd*, across the middle, which divides it into two chambers, B B′. This diaphragm is perforated by a great number of small holes, for the passage of the vapour upwards during the process, and it is also furnished with several valves, which open upwards as shown at *e e*, whenever the vapour is in such quantity as not to find a free passage through the perforations. A pipe, V V, descends from this diaphragm nearly to the bottom of the lower chamber B, into a pan forming a steam-trap, and there is a valve on the top of this pipe which can be opened or shut at pleasure by means of a rod *t*, passing through a stuffing-box on the top of the vessel. Glass tubes at *x x* show at all times the level of the liquor in the chambers B B′.

The analyser C D E F consists of 12 chambers, *f f*, formed by the interposition of 11 copper diaphragms, *g h*, *g h*, &c., all perforated with numerous holes, and furnished with valves opening upwards, as in the large diaphragm *cd*. To each of them is attached a dropping pipe, *h h*, by which the liquor is allowed to flow from plate to plate: the upper end of each of these pipes projects an inch or two above the plate in which it is inserted, so as to retain at all times during the distillation a stratum of wash of that depth on each diaphragm; the lower end of each pipe dips a little way into a shallow pan lying on the diaphragm underneath, forming thus a steam-trap by which the escape of vapour through the pipe is prevented. The pipes are inserted at alternate ends of the diaphragm, as shown in the figure.

The column G H I K is divided in a similar manner into chambers by interposed copper plates or diaphragms. There are 15 chambers in this column; the lowermost 10, *v v*, constitute the rectifier, and its diaphragms are perforated and furnished with valves and dropping pipes, as in the analyser. The uppermost 5 of these frames form the *finished spirit condenser*, and are separated from the other 10 by a copper sheet or diaphragm, not containing the small perforations, but having a large opening at W for the passage of the spirituous vapour, and a dropping pipe at S. There is a neck above the opening W, rising an inch or so above the surface of the diaphragm, which prevents the return of any finished spirit by that opening. Under the dropping pipe S is a pan much deeper than those of the other dropping pipes, and from this pan a branch pipe, *y*, passes out of the apparatus, and carries the condensed, but still very hot spirits, to a worm or other refrigerator, wherein they are cooled. The chambers *v′ v′* of this finished spirit condenser are formed of plain unperforated diaphragms of copper, with alternate openings at the ends, large enough both for the passage of the vapour upwards, and of the condensed spirit downwards; the use of these diaphragms being merely to cause the vapour to pass along the pipes in a zigzag direction, and thus to be more perfectly exposed to their condensing surface. In every chamber, both of the finished spirit condenser and of the rectifier, there is a set of zigzag pipes, placed as shown in the plan, Fig. 719; each set of these pipes is connected with the others by the bends *l l l*, and they thus form one continued pipe, leading from the wash-pump, Q, to the bottom of the rectifier, whence it finally passes out, and rising up, enters the top chamber of the analyser, into which it discharges itself at *n′*.

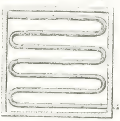

Fig. 719.

M is the wash charger, L a smaller wash vessel connected with it, and with the wash-pump. This vessel is called the *wash reservoir*, its use being to retain a sufficient reserve of wash, to prevent the apparatus being idle during the delay which the Excise regulations render unavoidable, between the emptying of the wash charger and the refilling of it from a new back.

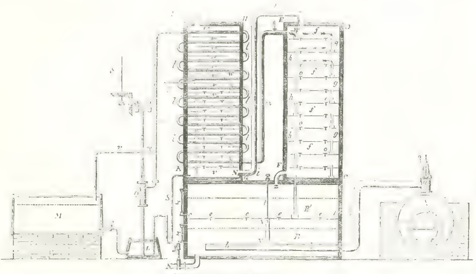

Fig. 720. COFFEY'S STILL.

During the distillation the pump Q is worked continuously, so as to supply the apparatus with a regular stream of wash. It is so constructed as to be capable of furnishing somewhat more than is necessary, and there is a pipe, *n*, with a cock on it, by which part of what is pumped up may be allowed to run back, and thus regulate the supply.

A is a steam boiler, which conveys steam into the bottom of the spent wash receiver by the pipe *b*, which, after entering the receiver, branches into a number of smaller pipes perforated with holes, by which the steam is dispersed through every part of the wash in which they are immersed: these perforated pipes are not shown in the engraving.

The action of this still is as follows:—At the commencement of an operation the wash pump is first set in motion to charge all the zigzag pipes, until the wash passes over into the analysers at *n'*. The pump is then stopped, and the steam let into the bottom of the apparatus by the pipe *b b*. The steam passes up through the chambers B B', and by the pipe *z* into the analysers, from whence it descends through *i i* to the bottom of the rectifier at N. It then rises through the chambers *v v*, enveloping the zigzag pipes, and rapidly heating the wash contained in them. When the attendant finds, by feeling the bends *l l*, that the wash has been heated in several layers of these pipes, (perhaps 8 or 10 layers,) he again sets the pump to work, and the wash, now boiling hot, or nearly so, and always in rapid motion, flows from the pipe *m* at *n'*, and passes down from chamber to chamber through the dropping pipes in the direction shown by the arrows in a few of the upper chambers. No portion of the wash passes through the small holes perforated in the diaphragms which separate the chambers. These holes are regulated, both in number and size, so as to be not more than sufficient to afford passage to the vapour upwards under some pressure. The holes, therefore, afford no outlet for the liquor, which can only find its way down in the zigzag course indicated by the arrows. It is evident, therefore, that the wash as it passes down is spread into strata as many times as there are diaphragms, and is thus exposed to the action of the steam constantly blowing up through it. As it descends from chamber to chamber its alcohol is abstracted by the passage of the steam through it, and by the time the wash has reached the large chamber, B, it is in the ordinary course of the operation completely deprived of its alcohol.

The wash as it descends from the analyser accumulates in the upper large chamber B', until that chamber becomes nearly filled, which when the attendant perceives to be the case by the inspection of the glass tube, he opens the valve of the pipe v, and discharges the contents of B' into B; then shutting the valve, the wash from the analyser again accumulates in B', and when it is a second time nearly full, the contents of the lower chamber B are discharged from the apparatus altogether, through the cock N, and the charge in B' is let down into B by opening the valve as before, and thus the process goes on so long as there is any wash to supply the pump. When all the wash is gone, a quantity of water is let into the reservoir L, and pumped through the pipes, to finish the process and obtain the last portions of alcohol. This winding up of the operation by sending water through the pipes takes place on the distillation of every back of wash, in consequence of an Excise regulation, which requires the distiller to keep the produce of each back separate from any other. Were it not for this regulation, the distillation would go on uninterruptedly, so long as there was any wash in stock; the addition of water for winding up would be necessary but once during the distilling period, and the manufacturer would save much time and fuel, at present wasted by these interruptions.

In the ordinary course of the operation, the wash is deprived of all its alcohol by the time it has reached the bottom of the analyser, but as a precautionary measure the chambers B' B are added, in each of which the spent wash is exposed for about half-an-hour to the action of the steam blowing through it.

There is a small apparatus, not shown in the Figure, by which a portion of the steam in the chamber B' is condensed, cooled, and made to flow constantly through a sample jar in which is a hydrometer, or two glass bubbles, one of the sp. g. 1,000 and the other 998. The attendant knows that all is going on well when these bubbles, or the lighter of the two, float in the sample. In this way the chamber B may be emptied without any risk of loss.

The course of the wash being understood, we will next trace that of the steam, which as it rises is first blown through the charges of spent wash in the chambers B' B: thence it passes up through the layers of wash on the 11 diaphragms of the analyser. In its passage it abstracts from these layers of wash their alcohol, depositing in its place an equivalent quantity of water. After traversing the whole of the analyser, the vapour, now containing much alcohol, passes by the pipe *i i* into the bottom of the rectifier, and as it ascends, it envelopes the pipes, heating the wash and at the same time parting with its more watery portion, which is condensed, and falls, in a boiling state, on the several diaphragms of the rectifier. By the time the vapour reaches the passage W, in the bottom of the finished spirit-condenser, it is nearly pure alcohol, and, as it is condensed by the wash in the pipes, and falls on the diaphragm, it is conveyed away by the pipe *y* to a refrigerator. At the top of the spirit-condenser is a large pipe R, which serves as a vent for the incondensible gas which is disengaged in the process, and this pipe also communicates with the refrigerator, so that, should vapour at any time be sufficiently elastic to pass out of the apparatus, no loss is sustained beyond the waste of fuel caused by condensing that vapour by the water of the refrigerator instead of the wash of the condenser. The liquor condensed on the several diaphragms of the rectifier, after being blown through by the vapour passing up from plate to plate, descends to the bottom in the same manner as the wash descends from chamber to chamber in the analyser: but this condensed liquor still contains a portion of alcohol, and it is conveyed by the pipes to the pump O, by which it is pumped up with the wash to be again distilled. A thermometer near E shows the attendant the temperature of the wash as it issues from the pipe *m* into the analyser, which is the only guide which he requires for managing the operation, for when the proper temperature is maintained the work goes on well: when the thermometer indicates too high a temperature, more wash should be let into the apparatus, and *vice versa*; the quantity being regulated by the cock on the pipe *n*. The difference of a few degrees above or below the proper heat is not, however, of much consequence.

The water for supplying the boiler passes through a long coil of pipe immersed in the boiling hot spent wash, by which means it is raised to a high temperature before it reaches the boiler. The vapour which passes through this apparatus is all condensed by the wash, not by the water; so that no heat is wasted. It is stated that about three-fourths of the fuel used with the common stills is saved by this apparatus. By the common process, to distil a gallon of proof spirits 12lbs. of coal are required, 9lbs. of which are saved by this apparatus. Supposing the whole quantity of spirits distilled in Great Britain and Ireland to be 36,000,000 gallons, and that the improved still is adopted, the saving of fuel would amount to 140,000 tons of coal per annum.

It will be seen from the above description, that Coffey's still, in its principle as well as most of the details, closely resembles the French stills already described. One feature peculiar to the British stills is their enormous size.[1] One of Coffey's stills, at Inverkeithing, distils 2,000 gallons of wash per hour, and there is one at Leith which distils upwards of 3,000 gallons per hour. Some of the store vats also rival those of the London porter brewers. 20,000 gallons of whiskey are sometimes stored in one vat.

Dr. George Wilson has kindly furnished the Editor with the following information respecting the stills used in the Scotch distilleries.

He says:—"Three kinds of still are in use in Scotland; 1. *Coffey's*, which is everywhere supplanting all others for the preparation of *grain* whiskey; 2. *Stein's*, which is the same in principle as Coffey's, and is used to a considerable extent in the preparation of *malt*-whiskey; 3. The old simple still, which continues to be largely employed, but only for malt-whiskey, and this is usually distilled twice. Coffey's still derives so large a per-centage of alcohol from the wash, that the old trade of rectifying spirit has ceased in this quarter, and the strongest commercial spirits of wine are made by a single operation. At Sunbury, they distil water as well as alcohol, and the latter is reduced to a drinkable strength by a suitable dilution supplied by the former. Coffey's still produces the strongest spirit, and takes no heed of flavour. Whiskey drinkers, however, do not love what chemists call the pure hydrated oxide of ethyle, and thus it happens, that less potent stills than Coffey's are employed to imbue the spirit with aroma. The still at Sunbury produces alcohol at 64 or 67 over proof. In an apparatus which is supposed to combine the advantages of Coffey's and Stein's, spirit is produced 16 or 20 over proof.

"The product of the Coffey still requires only dilution to be at once marketable. Most of the Scotch whiskey sold in England is manufactured by this still. It is characterised by the absence of any marked flavour, except in a very faint degree, in consequence of the method of distillation preventing the less volatile fusel oil, and other strong scented products of fermentation, from passing over with the spirit. Malt-whiskey (made from malted grain) contains those flavouring ingredients which certain connoisseurs prefer: the *small-still* whiskey of the Scotch smuggler, and the *potheen*, (the Irish equivalent of small-still, or *little pot*,) being prized for their *peat-reek*, or *smoke* flavour. In the manufacture of these malt whiskeys, in which potatoes and treacle or sugar are sometimes used, and sometimes raw grain, but this only to a small extent, the old-fashioned simple still, endlessly varied but generally with a high head, is employed. Two-thirds or more of what is called *malt whiskey*, and sold as such, is grain whiskey, flavoured with a dose of the most odorous malt spirit."

The manufacture of spirits is a fruitful source of revenue, and is closely watched over by the officers of excise. Their duties in this particular, as well as those of the distillers, are contained in a long and complicated act of parliament, with which it behoves them to be well acquainted, for there are penalties for the infringement of the various clauses amounting to many thousand pounds. The following is an abstract of Macculloch's account of these duties, which we preface with his own sensible remarks:—"There are perhaps no better subjects for taxation than spirituous and fermented liquors. They are essentially luxuries; and while moderate duties on them are, in consequence of their being generally used, exceedingly productive, the increase of price which they occasion has a tendency to lessen their consumption by the poor, to whom, when taken in excess, they are exceedingly pernicious. Few governments have been satisfied, however, with imposing moderate duties on spirits; but partly in the view of increasing their revenue, and partly in the view of placing them beyond the reach of the lower classes, have almost invariably loaded them with such oppressively high duties, as have entirely defeated both objects. The imposition of such duties does not take away the appetite for spirits; and as no vigilance of the officers or severity of the laws has been found sufficient to secure a monopoly of the market to the legal distillers, the real effect of the high duties has been to throw the supply of a large proportion of the demand into the hands of the illicit distiller, and to superadd the atrocities of the smuggler to the idleness and dissipation of the drunkard.'

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[1] Messrs. Wylie & Co. of Glasgow have sent us a drawing and description of Mr. Maxwell Miller's patent distilling and rectifying apparatus, which we have not been able to insert for want of space.

The prevalence and direful effects of gin-drinking in the latter part of the reign of George I., and the commencement of the succeeding reign, were so marked, that public attention was strongly drawn thereto. It was naturally thought that the cheapness of spirits, and the great number of public-houses, were the sources of this general evil; and, forgetful of the danger of extreme measures, the ministry of the period (1736) passed a stringent act, which prohibited altogether the use of spirituous liquors, except as a cordial or medicine. This attempt, not to regulate and repress the drinking of gin, but to abolish it altogether, was most unwisely made, and had an effect directly opposite to what was intended. The enormous duty of twenty shillings per gallon was laid on spirits, besides a heavy licence duty on retailers, and every encouragement was given to informers to seek out those who should vend the smallest quantity of spirits which had not paid the full duty, and to exact the penalty of 100*l.* for the offence. On the passing of this act, respectable dealers withdrew from the trade, and it fell chiefly into the hands of low and profligate characters, who, having nothing to lose, were not withheld by penalties from breaking through its provisions. The populace supported the cause of the smugglers and unlicensed dealers; informers were hunted down like wild beasts, drunkenness and crime rapidly increased, and in two years the act had become so contemptible, and was so openly set at nought, that policy as well as humanity forced the commissioners of excise to mitigate its penalties. Within those two years 12,000 persons were convicted of offences connected with the sale of spirits, and, in spite of all prohibitions, 7,000,000 gallons were annually consumed in London and its vicinity alone. Under such circumstances, government soon gave up the unequal struggle, the high duties were repealed, and moderate ones imposed in their room. The consequences were highly beneficial: an immediate stop was put to smuggling, and to the serious crimes and disorders connected with it, while gin-drinking, to say the least, was not increased by the change.

It has been too long the policy with respect to Ireland to exact heavy duties on spirits; and in consequence smuggling has been carried on to a great extent in that country. An Irish whiskey-still has been chosen by artists as a subject characteristic of the people, and at one time the attempts to put down illicit distillation met with so determined a resistance that the country was filled with anarchy and bloodshed. Any one found working an unlicensed still was subjected to transportation for seven years, and a heavy fine was imposed on the parish or manor where the still was found. This was intended to engage proprietors heartily in the work of putting down the practice. In 1822, when the duty on spirits was 5*s.* 6*d.* per gallon, the annual consumption of spirits in Ireland was estimated at 10,000,000 gallons, while scarcely 3,000,000 paid duty, so that 7,000,000 must have been illegally supplied. This vast amount of smuggling was carried on in the teeth of the above heavy penalties, and in despite of the utmost exertion of the military and police to prevent it. To put an end to such evils the duties were in 1823 reduced from 5*s.* 6*d.* to 2*s.* 4*d.* (imperial gallon), and with the most satisfactory results. The consumption of spirits was not increased thereby, but a considerable increase to the revenue resulted from the substitution of legal for illegal distillation, while the evils of smuggling became nearly extinct. An extraordinary decrease in the consumption of spirits in Ireland took place in 1839, which is chiefly to be ascribed to the great exertions made at that time in the Temperance cause.

The history of the spirit trade in Scotland corresponds in a great measure with that of Ireland. While the duties were high, the quantity of illegally distilled spirits annually produced in the Highlands amounted to about 2,000,000 gallons. In corroboration of this it is stated, that in 1821 only 298,138 gallons were brought to the charge in the Highlands, and of these 254,000 gallons were permitted to the Lowlands, leaving only 44,000 gallons for the consumption of the whole of the Highlands, a supply which would hardly be sufficient for the demand of two moderately populous parishes. During this state of things the natural results exhibited in various districts were thus alluded to in a letter from Captain Munro, of Teaninich, to the Commissioners:—"The moral effects of this baneful trade of smuggling on the lower classes are most conspicuous, and increasing in an alarming degree, as evidenced by the multiplicity of crimes, and by a degree of insubordination formerly little known in this part of the country. In several districts, such as Strathconon, Strathcarron, &c., the excise officers are now often deforced, and dare not attempt to do their duty; and smuggled whiskey is often carried to market by smugglers escorted by armed men, in defiance of the laws. In short, the Irish system is making progress in the Highlands of Scotland." The remedy in this case, as in the other, was the reduction of the duty. It was lowered in 1823 from 6*s.* 2*d.* to 2*s.* 4¾*d.*, and in 1830 was slightly raised to 2*s.* 10*d.*, 3*s.*, and 3*s.* 4*d.* The influence of the reduction in 1823 was to double the consumption of duty-paid spirits, while at the same time illicit distillation was all but suppressed.

Before the Irish and Scotch duties were lowered, the duty on English spirits had been as high as 11*s.* 8*d.* per gallon. This high duty and the restrictions under which the trade was placed were productive of the worst effects. They went far to enable the distillers to fix the price of spirits, and consequently to raise it much beyond that which was sufficient to repay, with a profit, the cost of the manufacture and the duty. The commissioners found in 1823, that "when corn spirits might be purchased in Scotland for about 2*s.* 3*d.* a gallon, raw spirits could not be purchased in England for less than 4*s.* 6*d.* ready money, and 4*s.* 9*d.* credit, omitting, in both cases, the duty." In consequence, smuggling was carried on to a great extent in England; and the large profits made by the smugglers caused clandestine importations from Scotland and Ireland. To obviate these inconveniences, and at the same time to neutralize the powerful additional stimulus that the reduction of duties in Scotland and Ireland would have given to smuggling, had the duties in England been continued at their former amount, the latter were reduced in 1826 to 7*s.* a gallon, facilities being at the same time given for the importation of spirits from other parts of the empire. There was a great objection made to this, on the ground that it would increase drunkenness, but these fears have proved groundless. The consumption of British spirits in England and Wales in 1823 was estimated at 5,000,000 gallons; and it appears that in 1844 it amounted to 7,719,159 gallons, producing 3,023,115*l.* of revenue. Now, making allowance for the increase of population, and for the check given to adulteration and smuggling, and considering also that the consumption of foreign spirits was not greater in 1843 than in 1823, it is fairly estimated that the practice of spirit-drinking, although acknowledged to be far too prevalent, has not increased within the last twenty years. All these instances sufficiently prove that any attempt to check the excessive practice of spirit drinking in a country by imposing heavy duties and restrictions, is so far from having the desired effect, that it actually promotes the consumption of spirits, and leads to a whole catalogue of evils in the shape of adulteration, smuggling, vexatious informations, tumult, and rebellion against constituted authorities.

In 1860 there were distilled 7,868,525 gallons of proof spirits in England; 13,946,536 gallons in Scotland, and 6,474,670 gallons in Ireland, the total being 28,289,731 gallons; an increase of 632,010 gallons over that of 1859. The duty was paid on 21,873,384 gallons for the United Kingdom, a decrease of nearly 2½ million gallons, the duty having been raised to 10*s.* per gallon, producing the sum of £9,702,807. The duty was paid on 10,108,522 gallons in England; 6,428,549 in Scotland; and 5,336,313 in Ireland. The total quantity of British spirits exported in the year was 1,907,200 gallons, and 469,281 gallons of British compounds and spirits of wine. The quantity bonded amounted to 10,586,498 gallons, of which 6,419,787 were in Ireland. There were also produced 36,202 gallons of methylic alcohol sold by the excise, and 299,366 gallons sent out by persons licensed to sell the same.

The following are the imports of spirits for the years named.—

	1858.	1859.	1860.
Rum . . . . . *proof gallons*	3,427,465	[illegible]	[illegible]
Brandy	[illegible]	[illegible]	[illegible]
Geneva	[illegible]	[illegible]	[illegible]

In 1861 the number of gallons of spirits charged with duty was 8,952,174, and the number free of duty for exportation was 972,434 for England, while for Scotland the numbers were 6,070,091 and 3,400,776, and for Ireland 5,022,894 and 79,512.

The number of gallons for the United Kingdom for the year ending December 31, 1861, is as follows:—

Spirits charged with duty . . . . *gallons*	[illegible]
Free of duty for exportation	[illegible]
Total . . .	[illegible]

The Customs' duties on the imports of 1861 were, for rum £1,755,129, for brandy £833,513, and for Geneva £52,615.

The quantities of spirits remaining in the warehouses under bond on 31st December, 1861, were as follows:—

Rum . . . . *proof gallons*	[illegible]
Brandy	[illegible]

DIVIDING ENGINE. See GRADUATION.

DIVING BELL. We have seen in our article AEROSTATION with how little success man has endeavoured to extend his dominion to the regions of the air. We have now to trace the history of his more successful attempts to explore the depths of the sea or of rivers, for the purpose of collecting such valuable articles as pearls, sponges, coral, &c., of recovering articles lost by shipwreck, laying submarine foundations, and mining or exploding the rocks which obstruct the entrance of harbours, &c.

The early history of the art of diving, like the early histories of most of the useful arts, contains many wonderful narrations, evidently as much the result of the imagination as of the scientific observation of the narrators. These we pass over in silence. The necessity for a regular supply of atmospheric air reduces the powers of the unassisted diver to very narrow limits; for with the greatest known capacity of lungs, and the strongest inspiration, there is no authentic case of a man being able under ordinary circumstances to take in a supply of air sufficient to maintain him under water for two minutes. In ordinary cases, a sense of suffocation is experienced after the submersion in water of half a minute. Dr. Halley relates the case from his own observation of a Florida Indian diver at Bermuda, who could remain under water for two minutes; but this is doubtless an extreme case. Admiral Hood tested the much-vaunted powers of the Indian divers, with a watch in his hand, and found that in no case could any one of them remain submerged more than a minute. Halley relates that those who dive in the Archipelago for sponges take into their mouths a piece of sponge, dipped in oil, with the view, as he supposed, of inhaling the air contained in the sponge: the real reason, however, appears to be for the purpose of calming the small waves on the surface which prevent the light from being transmitted to the bottom: by ejecting a little oil from their mouths, it rises to the surface, and spreading upon it, produces smooth water, and gives a steady light at the bottom, which is necessary to assist the divers in finding the small objects they are in search of. It is exceedingly difficult to hold the breath under water, on account of the great fluid pressure on the chest, which increases with the depth. Most divers, by continuing to dive for any length of time in deep water, have blood-shot eyes and a spitting of blood, arising from the great exertion. Many of the natives of the South Sea Islands are such expert divers that if a nail or a piece of iron be thrown overboard, they will jump into the sea after it and recover it.

Attempts have been made at various times by ingenious men to contrive some form of dress, such as would enable the diver to remain under water for an indefinite length of time, his respiration being carried on by means of flexible tubes, communicating with the air above; fresh air being forced down one pipe by bellows or other means, and allowed to return by the other. To prevent the great pressure of the water on the chest of the diver, a sort of water armour, made tight by leather, was contrived. This answered tolerably well in depths not exceeding twelve or fifteen feet. At greater depths, it was necessary to the free motion of the diver to have his limbs exposed; and the pressure on them was found to be so great as to obstruct the circulation of the blood, while those parts of the body encased by the armour being relieved from pressure, the blood was forced from the limbs into them, thus producing much suffering. One of the best forms of armour was Klingert's, which has often been described. In other forms of apparatus, the diver was completely shut up in a vessel, and moved about by means of tackle connected with the ship above. Submarine boats have also been proposed at different times, for the purpose of destroying an enemy's shipping. These have not been very successful; and we trust the time will not again arrive when such inventions will be, if under any circumstances they can be, desirable.

All these contrivances have been for the most part superseded by that simple and beautiful machine, the diving bell, which has already been of such vast service in subaqueous operations. By its means, too, three or more men can descend in company, move about with perfect freedom, and employ tools for accomplishing the intended object at the bottom of the sea; they can also descend to a greater depth than by any other contrivance, and continue a very much longer time below, and, if necessary, they can carry a light down with them for the purpose of guiding their works.

Several allusions are made to diving machines, more or less resembling the diving bell, previous to the time of Dr. Halley, who has the merit of, at least, rendering former attempts practicable. Halley's bell was of wood, of the internal capacity of about sixty cubic feet; its form a truncated cone, the diameter at top being three feet, and at bottom five. It was covered with lead, so that it could sink empty, and the weight was so distributed at the bottom that it would go down perpendicularly. Light was admitted at the top through a strong clear glass, and the hot vitiated air was let out through a cock at the top. About a yard below the bell was a stage suspended by three ropes, each loaded with about a hundredweight. The bell was suspended from the mast of a ship, carried overboard clear of the ship's side. Air was supplied to the bell by means of a couple of barrels of about 36 gallons each, cased with lead so as to sink when full of air: the bung-hole at the lowest part was left open, so that a portion of water entered the casks, and condensed the air during their descent: a leathern hose was attached to the top of each cask, the open end of which hung down by a weight below the bung-hole, so that the air could not escape unless this open end were raised. These two buckets were fitted with tackle, and made to ascend and descend alternately like two buckets in a well. The hose of the descending barrel being taken up into the bell, the water would rush into the cask, drive out the air before it through the hose into the bell, and the cask being thus filled with water, was drawn up, when the water flowing out, its place was supplied with air; while in the meantime the other cask would in its turn be discharging its contents into the bell. In this way, Dr. Halley states that he, with four others, have continued in the bell, in 9 or 10 fathoms water, for an hour and a half, without inconvenience. "The whole cavity of the bell was kept entirely free from water, so that I sat on a bench which was diametrically placed near the bottom, with all my clothes on. I only observed that it was necessary to be let down gradually at first, as about twelve feet at a time, and then to stop and drive out the water that entered, by receiving three or four barrels of fresh air before I descended further; but being arrived at the depth designed, I then let out as much of the hot air that had been breathed as each barrel would replenish with cool, by means of the cock at the top of the bell, through whose aperture, though very small, the air would rush with so great violence as to make the surface of the sea boil, and to cover it with a white foam, notwithstanding the great weight of water over us."

In 1721, Dr. Halley invented additional apparatus to enable the diver to go out from the bell to some distance, and remain a sufficient time in the sea. The man was supplied with air by a bell or cap of lead with glass eyelets, which completely covered his head, and was supplied with air from the bell by means of a flexible tube. To diminish his buoyancy at this depth, weights of lead were attached to his girdle and clogs of lead to the feet.

Improvements or variations were made in Dr. Halley's bell by Mr. Martin Triewald, and by Mr. Spalding. Some of these were ingenious and were admired at the time; but the simple form of bell which is now in use seems to be preferred to the more complicated machines. To Smeaton belongs the merit of applying the diving bell to the operations of engineering, to which it has since rendered such essential service. About the year 1779, Smeaton used it in repairing the foundations of the piers of Hexham Bridge, which had been undermined by the violence of the current sweeping away the gravel from under the floor timbers of the caisson in which they were founded. In this way he succeeded in underpinning the foundations of some of the piers. The accident which followed in 1782, when the whole structure was carried away by a sudden and violent flood, only proved the insufficiency of the natural bed of the river. [See BRIDGE, Fig. 294.]

To Smeaton also belongs the merit of inventing the modern form of bell, consisting of cast-iron. The first bell of this kind was made about 1788, for carrying on the works at Ramsgate harbour. This bell weighed 50 cwt.; it was heavy enough to sink itself without the addition of external weights: its height was 4½ feet, its length the same, and its width 3 feet, thus affording space for two men to work under it at a time.(1) It was also peculiar to this machine that the men were furnished with a constant supply of fresh air without any attention on their part, by means of a forcing air-pump contained in the boat above. The bottom part of this bell B B′, Fig. 722, was made very thick to give it sufficient weight, and in the crown, Fig. 721, were 8 round holes, each furnished with a lens 4 inches diameter, fitted into a brass cell and then screwed into the cast-iron. In the centre was a hole *h*, to receive a brass screw at the end of the leather pipe for introducing the air. This hole on the under side had a leather valve stretched over it to prevent the return of the air, and also a grating of iron across it to support the valve against the pressure when it was shut. The valve was a square piece of leather stretched over the hole and fixed to the iron by a screw at each corner, and so tight as to prevent it from opening to admit the air: *e e* are two strong eyes to receive the chains which suspend the bell, and there are similar eyes within the crown, to suspend an iron link I, to which chains may be attached. The whole is cast in one piece: *s s′* are two seats for the divers to sit upon as they descend; but these turn up upon hinges when they are at work.

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(1) A larger bell, 6 feet long and 4 broad, was subsequently used.

The pier which was afterwards built upon the foundation cleared by this diving bell, was founded by caissons, [See BRIDGE;] but not being done very substantially or with large stones, the work had become so bad as to require renewal in some places, and in others to be defended by an apron or outside wall of very solid masonry, which was laid by means of the diving bell. The machinery employed is shown in elevation, Fig. 723, and the following description of its use applies to the method introduced by Smeaton. The cast-iron bell is seen in section attached by two chains to the three-sheaved block *b*; another block *b′*, with three sheaves is supported between two long timbers T T′. These are united to form one frame, and to strengthen them, king-posts K, and riders R R′, are erected upon them, and very strongly tied by iron straps and wooden knees. These beams traverse upon a centre pin *p*, which is fixed into a very heavy stone; and they are also supported by small wheels which run upon a railroad I, which is curved to a segment of a circle. The extremity T′ of the frame has a heavy stone attached to it, to balance the weight of the bell appended from the opposite end. The fall of the tackle is conducted through a block *x*, to a capstan by which it is taken up or let down. This machine is placed upon the top of the pier wall W, at the foot of which, the stones shown as dotted are to be laid by the divers. In order to move the bell nearer to or further from the wall, the block *b′* is moved in the beams: to haul it in, a pair of blocks *e f* are used, and it is drawn out by a rope passing through a block at T, and then to another pair of blocks not shown in the figure; to move it sideways, two pair of tackles are applied, one pair shown at *l m*, and another pair on the other side not shown. P is the leathern pipe conducted from the bell to the forcing pump N, fixed on board the boat, and is worked by the lever *n*; *r* is a rope extended from the bell to the boat, and being shorter than the pipe, it prevents it from being broken or stretched by the wind or tide carrying the boat away; and it is also secured to the pier by the rope *r*. The man at the pump N forces down so much air to the bell as will cause the air to flow out beneath the lower edge of the bell and rise in bubbles to the surface: as long as this continues he knows that the divers are well supplied with air. Signals are given by the bellman with a hammer struck on the inside of the bell: thus, 1 blow signifies "More air;" 2 blows, "Stand fast;" 3, "Heave up;" 4, "Lower down;" 5, "To eastward;" 6, "To westward;" 7, "From the wall." The stones are all prepared and jointed together with dovetails before they begin to lay them; and the first thing to be done is to make the foundation perfectly level and true. The loose sand &c., is removed by dredging from above in the usual manner, and then the bell with two men in it is let down to the bottom, which at Ramsgate is a hard chalk rock: when it stands thereon, it lays the chalk dry to the level of the bottom edge of the bell; but if the surface is uneven, the bell cannot descend so low but that it will leave 6 or 8 inches of water on the bottom. The surface of this water is the level they work to, and by cutting away every eminence which rises above the water they soon obtain a perfectly level surface. They work with a small pick, made something like a narrow adze, and as the chalk is not hard, the work proceeds rapidly. When they have accumulated a certain quantity of rubbish, they knock three times on the bell, to order the people to draw it up, till they, standing on the bottom, find themselves knee deep, then two knocks to stand fast. They now take in a shallow basket let down from above, and fill the rubbish into it, then pull the rope to order it to be drawn up, and strike four times on the bell that they may be lowered down to proceed with their work. Having in this way hewed away the surface till the water standing equally all over it shows it to be a level plane, they give orders to be removed to a new situation, yet at so small a distance that part of the surface just levelled is still beneath the bell: in this way a uniform plane is preserved, and the rock is prepared for the stone work without any other level than the water. The stones are hoisted by a crane, moving on wheels so that it can be wheeled upon the pier to the required spot close to the diving machine. The first stone is taken up by it out of the boat, the hooks of the crane rope being put in the ring of a lewis; the stone is turned round into the position in which it is to be laid, and lowered to the bottom as close as is convenient to the bell; then by shaking the crane rope, its hook is disengaged from the ring of the lewis, and without moving the crane the rope is drawn up. The bell is then drawn up 2 or 3 feet, and by the various tackles it is moved to such a position that the centre of the upper block comes exactly under the hook of the crane rope: this like a plumb-line shows that the bell is brought exactly over the stone. The bell is now lowered down upon it, and the divers reeve a strong chain through the ring of the lewis, and also through a ring or iron loop, L, Fig. 722, in the top of the bell. On heaving up, the stone with the bell

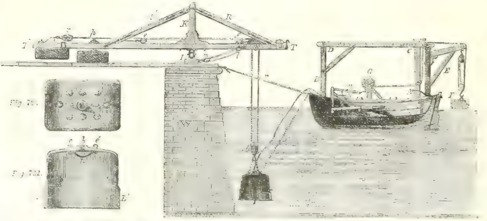

Fig. 7[illegible].—SMEATON'S ARRANGEMENT FOR CARRYING ON THE WORKS AT RAMSGATE HARBOUR.

raised off the ground, and the men direct by signals how it is to be moved in order to convey it to the destined spot; which being carefully done, they proceed with the bell to take up a second stone, which had in the meantime been lowered to the bottom by the crane. No cement is used to unite these stones, as they are all dovetailed into each other, and the joints are then wedged quite fast by oak wedges driven down, and lastly by sand rammed very hard into all the interstices between the dovetails. The great weight of the stones defends them from the action of the sea, every one of the lower course being 3 feet-wide by 4½ long, and 2 feet 3 inches thick. Notwithstanding their great weight, the tackle for the bell is so well made as to lift the stone with the bell altogether, and move it with great precision. The crane boat used for building the pier, when it comes above water, as well as for assisting the operations of the diving bell, is also shown of a reduced size in the figure. It is a strong boat of 30 or 40 tons burthen, with a frame ABCD, erected upon it to support the crane gibbet E, from which the stone F is suspended by the rope and raised by the windlass G with cog-wheels.[1]

Since the completion of Ramsgate Harbour, the diving bell has been applied by Mr. Rennie and other engineers with great success to a variety of similar operations in Dublin, Donaghadee, and other harbours in Ireland, at Holyhead and Portpatrick on this side of the channel, and in other parts of the kingdom. The diving bell has also been used in bridge-building, and in the repairs of bridges. In the construction of the Lary Bridge, near Plymouth, Mr. Rendel caused the pile heads to be levelled and the spaces between them paved by means of a diving bell.[2] The work was executed with safety and expedition, and Mr. Rendel expresses his conviction that diving bells may be employed by the bridge-builder in a variety of cases with much greater advantage and economy than coffer dams.

The common rectangular diving bell is subject to considerable vibration in rapid streams. It has been proposed by Col. Pasley and others to attach boat-shaped ends to it: on descending in a bell thus provided at the half ebb of a strong flood tide, the Colonel found it perfectly steady.

It is not often that a competent observer will condescend to publish his observations of phenomena which are supposed from their daily occurrence to be perfectly well known. There are, however, numerous facts of great and permanent interest connected with the diving bell, which can only be accurately observed and faithfully recorded by a scientific man. Such a narrative has been given by Dr. Colladon of Geneva, the results of whose experience were given in a paper read before the Royal Society of Edinburgh in April, 1821; from which we gather the following particulars. Dr. Colladon, being in Ireland in September, 1820, had an opportunity of going down in a diving bell then in use at Howth Harbour, near Dublin. The weather at the time was very fine, but the wind rather high, and the sea rough. The party got into a boat at 11 o'clock, A.M., and in a few minutes came alongside a vessel to which the diving bell was attached. The workmen were then at the bottom of the water, employed in clearing the entrance of the harbour. The bell was a kind of oblong iron chest, cast in one single piece, open below, 6 feet long, 4 broad, and 5 high: it weighed 4 tons, it was 3 inches thick at bottom, and half that thickness at top. It was cast in London, and, including the necessary apparatus and the air pump, cost about 200*l*. The bell being a great deal heavier than the water which it displaced, descended by its own weight. The upper part was pierced with 8 or 10 holes, in which were fixed the

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[1] "Historical Report on Ramsgate Harbour, [illegible] of and addressed to the Trustees by John Smeaton, C.E. F.R.S. and engineer to Ramsgate Harbour, [illegible]" Smeaton's Reports, vol. iii. Also Edinburgh Cyclopædia, art. *Diving Bell.*

[2] This diving bell was [illegible] it was made of [illegible] tight by means of strips of [illegible] inner [illegible] was also covered with [illegible] fully saturated. Its weight when [illegible] was [illegible] required from [illegible] at 25 feet of water. See "Transactions of the Institution of Civil Engineers." Vol. I. London: [illegible]

same number of thick convex glasses, which transmitted the light. The glasses or lenses were fixed in the top of the bell by means of a copper ring screwed up against the glass, between which and the bell a coat of putty was laid, and then screwed up hard, so as to make it air-tight. The top was pierced with another hole, about an inch in diameter, for receiving a long flexible leather pipe, intended to introduce into the bell the air compressed from above by a forcing pump. In the inside of the bell was a valve, which served to close the aperture, and prevent the air from escaping. In the interior were two small benches on opposite sides of the bell, with a foot-board between them. There was room enough for 4 persons. From the middle of the roof descended several strong chains, intended to sustain a kind of iron basket, in which were placed the stones or other matters to be carried up. The bell was suspended by the centre with strong ropes, and managed by means of a movable crane, erected on the deck of a small vessel. The party, consisting of Dr. Colladon, a friend, and two workmen, got into the bell, which was sufficiently elevated above the surface for that purpose, by means of a boat placed underneath it. They descended so slowly that they did not notice the motion of the bell; but as soon as the bell was immersed in water, they felt about the ears and the forehead a sense of pressure which continued increasing during some minutes :—

"I did not, however, experience any pain in the ears; but my companion suffered so much, that we were obliged to stop our descent for a short time. To remedy that inconvenience, the workmen instructed us, after having closed our nostrils and mouth, to endeavour to swallow and to restrain our respiration for some moments, in order that, by this exertion, the internal air might act on the Eustachian tube. My companion, however, having tried it, found himself very little relieved by this remedy. After some minutes we resumed our descent. My friend suffered considerably: he was pale, his lips were totally discoloured, his appearance was that of a man on the point of fainting; he was in inexpressibly low spirits, owing, perhaps, to the violence of the pain, added to that kind of apprehension which our situation unavoidably inspired. This appeared to me the more remarkable, as my case was totally the reverse. I was in a state of excitement resembling the effect of some spirituous liquor. I suffered no pain, I experienced only a strong pressure round my head, as if an iron circle had been bound about it; I spoke with the workmen, and had some difficulty in hearing them. This difficulty of hearing arose to such a height, that during 3 or 4 minutes I could not hear them speak. I could not, indeed, hear myself speak, though I spoke as loudly as possible; nor did even the great noise caused by the violence of the current against the sides of the bell reach my ears. After some moments we arrived at the bottom of the water, where every unpleasant sensation almost entirely left us. We were then 27 feet below the surface. I confess that the recollection of the great depth, joined to the idea that if the smallest stone, or other matter, should obstruct the action of the valve, the bell would be instantly filled with water, did not fail to create for a short time a kind of uneasiness. One of the workmen, however, to whom I imparted my thoughts on that subject, desired me, with a smile, to look at one of the glasses placed above us, which I observed to be so much cracked in the middle, that bubbles of air were continually escaping. We breathed during the whole of our stay under water with much ease. We experienced now and then a great heat. Our perspiration was sometimes copious, and sometimes there suddenly came over us so thick a vapour as to prevent my seeing the workmen placed opposite me; but as, by means of their signals, they constantly sent us from above pure air in so large quantities that a great part of what was contained in the bell made its escape with great violence, this inconvenience very soon disappeared. Our pulse was not affected."

Mr. Bald, who went down two days before in another part of the harbour, took with him a thermometer, and found the temperature of the air at the surface and in the inside of the bell to be 63° Fahr., whilst the temperature of the water within a foot of the bottom (that is to say, 19 feet below the surface,) was 56° Fahr. "The light which we had in going down and at the bottom of the sea was very strong. Mr. Bald could distinguish very easily in descending a great number of fishes, and other marine animals, which fled at the approach of the diving bell. The sun shone bright, and I could write and read very easily. We gathered some fuci. We took some marine animals, and obtained several pieces of rock. That part of the bottom of the sea which did not present any rock, was composed of sand and pebbles. The current of water was very violent; the colour of the water, as seen through the glasses, seemed to us to be of a light green; in the bell, where we had about 10 or 12 inches of it, it was quite colourless. Having remained more than an hour at the bottom, and having seen the men work as easily as in the open air, they made some signals, and we ascended, fully satisfied with what we had seen, and convinced of the facility and safety of these submarine operations. Before we went down they had lost their basket at the bottom of the water, and in order to find it again, they were obliged, in using their signals, to have the bell moved in every direction, which gave us the advantage of becoming well acquainted with the method they employed in making themselves understood. In going up the sensations which we experienced in the head were very different from those which we felt in descending. It seemed to us that our heads were growing larger, and that all the bones were about to separate. This disagreeable sensation, however, did not last long; we were in a short time above the surface, not only much pleased with what we had seen, but also with the idea of emerging safe from our narrow prison."

The signals made use of by the workmen are very simple; they consist in a smaller or greater number of strokes given with a hammer against the sides of the bell. They are easily heard on board, though no noise made above reaches the bell below. There is north and south end fixed to each bell, and which is always attended to by those on board, so that they can be moved with accuracy whenever they want to work, either south, north, west, or east. The signals for the various operations are as follow:—1 stroke means, "More air," or "pump strong;" 2, "Stand fast," which is applicable to all motions; 3, "Hoist;" 4, "Lower;" 5, "More south;" 6, "North;" 7, "Front;" 8, "Back;" 9, "Lower down the bucket;" 10, "Hoist up the bucket loaded;" and so on. The men also send up a note of what they want upon a label, which is instantly attended to if practicable, or some intimation sent down to them that it cannot be done. This is effected by means of a cord, one end of which is in the bell, and the other upon deck. It is by the signals above described that the bell is moved from one place to another in search of stones. This is effected by raising the bell a few feet from the bottom, and then, by the aid of the moorings of the ship, the bell sweeps along in any desired direction; as soon as a large stone is discovered a signal is made, the horizontal movement is stopped, and the bell lowered over the stone. If the bell be a little aside the workmen can, by standing in the bottom of the sea, and pressing with their shoulders against the bell, make it swing a foot or two in any direction, as it is suspended from an outrigger at some height from the vessel's deck. The men at Howth are principally occupied in clearing the entrance to the harbour. They are paid by the ton weight for what they quarry, and send up, viz.—6*s.* 6*d.* per ton for very hard rock, that has chiefly to be blasted with gunpowder; 5*s.* 5*d.* per ton for easier quarried rock; and 4*s.* per ton for detached stone, gravel, and mud. At this rate they are able to earn on an average 20*s.* per week all the year round. Their tonnage of rock averages 3½ tons per day, and detached stone 5½ tons for 4 men. This method of blowing up rocks by aid of the diving bell, as practised in Ireland, is as follows:—Three men are employed in the bell: one holds the jumper or boring iron, the other two strike alternately quick smart strokes with hammers. When the hole is bored of the requisite depth, a tin cartridge filled with gunpowder about 2 inches diameter, and a foot in length is inserted, and sand placed above it. To the top of the cartridge a tin pipe is soldered, having a brass screw at the upper end. The diving bell is then raised up slowly, and additional tin pipes with brass screws are attached, till the pipes are about 2 feet above the surface of the water. In the old practice the tube was filled with powder in a train and fired; but in many instances the heat melted the solder of the pipe, and the water entering extinguished the fire. The improved method is to leave the tube empty. The man who is to fire the charge is placed in a boat close to the tube, and to the top of the tube a piece of cord is attached, which he holds in his left hand. Having in the boat a chaffer with small bits of iron red hot in it, he with a pair of nippers takes one of the bits of hot iron and drops it down the tube, which instantly ignites the powder and blows up the rock. A small part of the tube is destroyed next the cartridge, but the greater part, which is held by the cord, is reserved for future service. The workmen in the boat experience no shock by the explosion; the only effect is a violent eruptive ebullition of the water, arising from the explosion; but those who stand on the shore and upon any part of the rocks connected with those which are blowing up, feel a very strong concussion, similar to the shock of an earthquake. A certain depth of water is necessary for safety, probably at least 12 feet. The workmen cannot go down and work when the sea is very rough, as the swell would prevent them from settling on the bottom; and they are frequently annoyed with what is termed a *ground-swell*, when it is quite still at top. This is a sure prelude of a breeze of eastern wind, which seldom fails to set in soon after, if it has not prevailed at the time on the other side of the Channel.

The best and easiest time for going down is at low water, when there is less pressure; but amateurs prefer going down at high water, that they may have it to say that they were 20 or 30 feet below water in a diving bell. The workmen are generally down in the diving bell 5 hours in the day without coming up; and in summer one set of men are down ten hours one day, and 5 hours the other, and so on alternately. They work at all seasons of the year, and do not feel much difference in the temperature. The water is more chilly in the winter, and when they come up into the atmosphere they feel it rather cold after being heated by their exertions below. They do not complain in general of pains in the head, except those who are new to this employment, and they are at first affected in this way, and about the ears; but this soon wears off. The men are in general rather relaxed in their bowels, probably owing to their feet being constantly wet and cold. The superintendant stated he is generally troubled with looseness and a copious flow of urine, but that his appetite was greatly increased. He stated that he found it beneficial to take a little spirits on coming up; that the time never seemed long to him when below; that he has frequently been 7 hours under water, without ascending, and scarcely thought it half that time. None of the men became deaf, and it was thought in some cases to be of benefit to persons afflicted with deafness. One man who had been rather affected in his breathing was completely cured by *belling*.

DOCK. (Teutonic *dock*, from *dekken*, to cover, enclose, or protect.) An artificial basin or excavation for the reception of ships in rivers and harbours, for the purposes of repair, or for loading and unloading their cargoes out of the influence of the tide. They are constructed of brick, stone, or timber; with locks or flood-gates pointed to or from the tide, to keep the water in or out as may be required.

Wet docks are for the reception of ships to lie afloat while loading or unloading, with gates pointed from the tide, to keep the water in at low water. They are sometimes furnished with locks with double gates, in order to economise the water. A wet dock without gate is called a *basin*; but this term is often applied to any form of wet dock.

Dry docks become so by the ebbing of the tide when the gates are left open, or by shutting the gates at low water, and pumping out the water that remains; this is now usually done by steam power. Ships under repair are placed in dry docks; they are admitted at high water, and the gates are shut at low water; and when the repairs are completed the gates are again opened before the rise of the tide, and the vessel is hauled out of dock. Ships are also built in dry docks called *slips*.

"Wet docks are an improvement in navigation and commerce of the utmost importance, but of very modern date in this country: indeed, they owe their introduction entirely to the spirit of individual enterprise in commercial speculation. Liverpool might still have remained a poor fishing village but for its convenient docks, which not only produce to the town and corporation a large revenue, but ensure to the merchant every possible facility in refitting, loading, and discharging his ships, whatever their burden or their cargo may be, without being exposed to the risk of losing both ship and cargo in a rapid tide river; and at all events to an unavoidable delay, occasioned by distance, the weather, or the state of the tides."

The most important docks on the Thames are the East and West India Docks, the London Docks, St. Katherine's Docks, and the Commercial Docks. There are also important docks at Southampton, Liverpool, and Birkenhead, Bristol, Hull, Dundee, Goole, Leith, &c. A valuable article on this subject, full of practical information, will be found in M'Culloch's "Dictionary of Commerce," 1850.

DORNOCK, a kind of stout figured linen, first manufactured at a town in Scotland of the same name.

DRAGON'S BLOOD, a resin of a deep red colour, imported from the East Indies. Professor Brande says:—"The finest kind is in large red drops or tears, and is said to be the produce of *calamus draco*. It also occurs in masses of various degrees of purity, and in sticks enveloped in palm leaves, but these varieties appear more or less adulterated. Pure dragon's blood is of a deep red colour, soluble in alcohol, and ether, and in alkaline solutions." It contains a little benzoic acid, and its chief use is for tinting spirit and turpentine varnishes, for preparing gold lacquer, for tooth tinctures and powders, for staining marble, &c.

DRAINAGE is an art of very great importance in works of civil engineering, and in rural domestic economy: its object is to collect and convey away the refuse waters and other matters from lands, towns, and buildings. By its means swamps and fenny districts are converted into fertile land; the health of the inhabitants, whether of town or country, is greatly improved; fevers and agues which once were common entirely disappear. The injury done by stagnant water to arable soil is shown by its effects, as thus stated by Mr Stephens:[1] "Whilst hidden water remains, manure, whether putrescent or caustic, imparts no fertility to the soil; the plough, the harrow, and even the roller, cannot pulverize it into fine mould; new grass from it contains little nutriment for live-stock; and in old, the finer sorts disappear, and are succeeded by coarse sub-aquatic plants. The stock never receive a hearty meal of grass, hay, or straw from land in this state, they being always hungry and dissatisfied, and of course in low condition. Trees acquire a hard bark and stiffened branches, and become a prey to parasitic plants. The roads in the neighbourhood are constantly soft, and apt to become rutted; whilst ditches and furrows are either plashy, or like a wrung sponge, ready to absorb water. The air always feels damp and chilly, and from early autumn to late in spring the hoar-frost meets the face like a damp cloth. In winter, the slightest frost encrusts every furrow with ice, not strong enough to bear one's weight, but just weak enough to give way at every step, while snow lies long lurking in shaded corners and crevices; and in summer, musquitoes, green-flies, midges, gnats, and gad-flies, torment the cattle, and the ploughman and his horses, from morning to night; whilst in autumn the sheep get scalded heads, and are eaten up by maggots, during hot blinks of sunshine. These are no exaggerated statements, but such as I have observed in every county in Scotland, in hill, valley, and plain; and wherever such phenomena occur, it may be concluded that stagnant water lurks beneath the soil upon a retentive subsoil."

The same authority also states the benefits of thorough draining. He says:—"On drained land, the straw of white crops shoots up steadily from a vigorous braid, strong, long, and at the same time so stiff, as not to be easily lodged with wind or rain. The grain is plump, large, bright-coloured, and thin-skinned. The crop ripens uniformly, is bulky and prolific; more quickly won for stacking in harvest; more easily thrashed, winnowed, and cleaned, and produces fewer small and light grains. The straw also makes better fodder for live stock. Clover grows rank, long, and juicy, and the flowers large and of bright colour. The hay weighs heavy for its bulk. Pasture-grass stools out in every direction, covering the ground with a thick sward, and produces fat and milk of the finest quality. Turnips become large, plump, as if fully grown, juicy, and with a smooth and oily skin. Potatoes push out long and strong stems, with enlarged tubers, having skins easily peeled off, and their substance mealy when boiled. Live stock of every description thrive, show good temper, are easily fattened, and of fine quality. Land is less occupied with weeds, the increased luxuriance of all the crops checking their growth. Summer fallow is more easily cleaned, and much less work is required to put the land in proper order for the manure and seed; and all sorts of manures incorporate more quickly and thoroughly with the soil."

Mr. Black in his Prize Essay on Draining bears similar testimony. He is referring to the effects of draining on the estate of Spottiswoode in Berwickshire. "Bursts and springs which formerly disfigured entire fields, and which rendered tillage precarious and unprofitable, are now not to be seen; and swamps, which were not only useless in themselves, but which injured all the land around them, have been totally removed. The consequence is, that tillage can now, in those parts, be carried on without interruption, and with nothing beyond the ordinary expenditure of labour and manure; and a sward of the best grasses raised and continued on spots which formerly only produced the coarsest and least valued herbage. . . . The hurtful effects of rime or hoar-frost on vegetation is a circumstance familiar to all who have had experience of cold and elevated districts, or of low lands subject to exhalations, excluded from the influence of the sun and currents of air. The rime in these swampy hollows was found, even in the warmest seasons, to be productive of serious inconvenience and injury to the growing crops; and that chiefly at the period when the grain was approaching its mature state. This evil, it may be said, has been removed, or at least is now so little felt, that the grain produced in these very hollows has for many years escaped the smallest perceptible injury from this cause.

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[1] Manual of Practical Draining.

"Another effect which was still less contemplated, and has not less agreeably resulted from the drainage undertaken, has been the improvement of the trees and woodlands on the property. Considerable difficulty was experienced in nursing up the trees in the first stages of their growth; and often individual trees grew up with stunted stems and covered with parasitical plants, which always indicate unhealthy growth. Latterly this evil has been infinitely less felt, owing in a material degree certainly to the superior management of the woods themselves, but obviously also in a certain degree to the great dryness of the ground. Since several of the woods have been laid dry by under-drainage, the ground in many of the hollows has sunk so much, that the roots of the trees have been left standing up bare above the surface, with the appearance of crow's feet; and parts which were boggy and marshy, and in which sportsmen used to stick fast in hunting, are now perfectly solid, with a good sward of grass, over which they may now gallop with freedom."

The art of draining is usually supposed to be restricted to the carrying off of water; but in its more extended sense it includes *irrigation,* or the proper distribution of water over a surface, with arrangements for carrying it off when it has served its purpose. Hence, if the natural supply of water be deficient, it is the duty of the drainer to increase it; if excessive, to reduce it.

The importance and value attached to supplies of water in Eastern countries are illustrated in many beautiful passages of Scripture, showing that water-springs, rains, and dew, were the most esteemed among earthly gifts, and therefore the most appropriate to be the figures of spiritual blessings. Other passages show that the art of irrigation was known to the earliest husbandmen. It has been supposed that the annual overflowing of the Nile, and the benefits derived to Egypt by that means, first suggested the idea of artificial irrigation to the Egyptians, and that other nations learned the art from them. The Egyptians practised the art on a large scale, as the remains of their canals and vast artificial lakes testify. Various hydraulic machines were also used, some of which appear to have resembled the water-wheels of the fen districts of England, and to have been worked by the feet of men, after the manner of the tread-mill. This laborious method of watering the ground seems to have been common in Egypt during the sojourn of the children of Egypt in that land, for Moses drew the following remarkable contrast between the climate and customs of Egypt, where rain seldom falls, and the more genial climate of the promised land. "For the land whither thou goest in to possess it is not as the land of Egypt, from whence ye came out, where thou sowest thy seed, and *waterest it with thy foot,* as a garden of herbs; but the land whither ye go to possess it is a land of hills and valleys, and drinketh water of the rain of heaven," Deut xi. 10, 11.

The method of raising and distributing water in Egypt at the present time is thus described. Water from the Nile is collected at certain times in large cisterns on the banks of the river. For this purpose the screw of Archimedes was formerly used, but now leathern buckets, or Persian wheels, are employed: these machines are placed all along the banks of the Nile, from the sea to the cataracts. When the grain crops, or the saffron, melons, sugar-canes, &c., require watering, a plug is taken out from the bottom of the cistern, and the water which gushes out is guided from one rill to another by persons whose office it is to manage the flooding of the ground.

Sometimes the water is merely raised by wicker baskets, lined with leather. Each basket is managed by two men, and is held by cords between them. Lowering and filling the basket at the river, they swing it over the banks into the canal, which conveys it at once to the land requiring water.

In Bengal the fields are diligently watered, or they would yield little produce. Wells are dug in the highest parts, and by means of bullocks, and a rope over a pulley, water is raised in buckets, and carried in small channels to every part of the field. Without this diligent watering of the soil in hot countries, rice, which furnishes food to the greater part of the human race, could not be cultivated. Accordingly, over the vast region of Southern Africa, the irrigation of the land by means of rivers, brooks, lakes, and wells, is a labour essential to human life. A machine similar to the Persian wheel is used in China for raising water.

In Southern Europe, also, irrigation is extensively carried on. In Italy, especially on the banks of the Po, it was practised long before the time of Virgil, and is zealously continued to this day. The waters of all the chief rivers of Northern Italy, as well as of numerous minor streams, are thus employed. From Venice to Turin, the entire country is said to be one great water-meadows, for the watering is by no means confined to grass lands, but is conveyed into the hollows between the ridges in corn lands, is distributed over the lowlands, where rice is cultivated, and is carried round the roots of vines. It was from Italy that the practice gradually spread throughout the South of France, and from thence to Spain and Britain.

The conducting of water from rivers and canals, and measuring it out in certain quantities, is consequently an important business of Southern Europe, and also forms a nice part of the science of engineering. In Lombardy, the water of all the rivers belongs to the State. In the Venetian territories the government not only claims the rivers, but also the smallest springs, and even collections of rain water. In renting the water of rivers from government, contracts are made to pay so much for the use of the water for an hour or half an hour at a time, or for so many days at certain periods of the year. A person desiring to irrigate his lands has the right of making a canal through another estate, which may lie between him and the river, being bound, however, to pay the owner the value of the land, and to avoid bringing the canal close by the mansion, or through the garden of the proprietor. The rent of land having the means of irrigation is one-third higher in Northern Italy than that of lands not so provided. As may be supposed, the utmost care is bestowed in economising the precious fluid.

The principle of the system of irrigation adopted in Lombardy is shown in Figs. 724, 725, in which *a a* is the feeder to *b b*, the irrigating channels: the water overflowing from these spreads over the rectangular sections of land between them, and thence passes into the draining channels *c c*, formed at a lower level than the supply channels, and is received in the common drain *d d*, through which it passes, and becomes the means of irrigating and draining to other similar districts in succession. The width of land between the channels *b* and *c* is about 22 feet, and the difference of level between the irrigating and the draining channels about 6 inches. These water meadows are in this way irrigated in summer during several hours, about once a-week, and in winter, from the end of September to the end of March the process is always in operation, except when the grass is being cut.

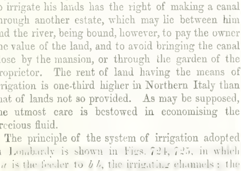

Fig 724.

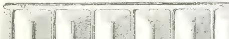

Fig. 725.

The methods of watering or draining districts and lands will vary with their respective levels; those adopted for high tracts being very different from low ones. As plains and valleys are more extensive than hill-tops and uplands, and are for the most part under cultivation, these necessarily receive a large amount of the drainer's care. Those low lands which form the margins of seas and rivers are frequently encumbered with a large surplus of water, which collects from the adjacent estuaries of large streams, or from rain or condensed vapour. If the level of the district is above that of the sea and the mouths of the rivers, the land may be kept tolerably dry by surface drainage. In some cases, the excess of water may be got rid of by tapping, or opening a communication with a lower and permeable stratum.[1] If the substratum be rock, surface-draining will succeed, but if it be bog, and its bed below the river or sea level, boring to the lower strata must be resorted to. If, however, the level of the district be below that of the waters, the land cannot be drained without embanking. In such case, in order to keep out the water, the embankments must be made substantial, and if the surface of the land cannot be raised to a higher level than that of the water, the surplus water must be got rid of by pumping. The system of embankments, carried on as it is to such a vast extent in Holland, has also been of great importance to our own island, by preserving its borders and extending its surface. In the fens of Cambridgeshire and Lincolnshire, the art of draining was at an early period forced upon the inhabitants as a matter of necessity. The bad effects of wet fields and moist pastures were recognised and deplored when the art of draining them was not understood in this country; "but on the sea-coast, and especially in the neighbourhood of the outfalls of rivers, the evil of neglect was too apparent to be disregarded: the ocean spread over its common bounds, and the waters of the river, choked up with silt, passed their limits; the pasture-fields became swamps; in some cases the land disappeared by degrees, and the inheritance of ages became merged in the boundless waters. The first work was to cut channels at intervals through the threatened district, (selecting the lowest levels for them where a choice was afforded,) in which the excess of water might be collected, and conducted to a main drain cut parallel to, or at an angle with, the coast or river; the transfer of the water from one to the other, and from the main to the sea or river, being, when necessary, regulated by sluices. The earth removed from these collecting and main drains, being cast up on either side of them, at once increased their available depth, formed boundaries to the passing water, and raised causeways for the passage of men and animals.

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[1] An account of *drainage*, as these operations are called, will be found in our article on ARTESIAN WELLS, p. 80 *ante*. A considerable portion of this article, as well as the article AGRICULTURE, may be consulted in connexion with DRAINAGE. See also SEWERS.

Thus arose the combined arts of draining and embanking."[1] The reader who is interested in this subject will do well to study the accounts given of the various methods adopted for draining the districts of the fens, a short account of which may be appropriate here.

The *Bedford Level* is a term applied to a vast tract of about 400,000 acres of low land, extending into the counties of Northamptonshire, Huntingdonshire, Cambridgeshire, Lincolnshire, Norfolk, and Suffolk. It is bounded by high lands, which encompass it almost in the form of a horse-shoe. In that part of the Level which runs into Northamptonshire, and extends between Peterborough and Crowland, *Peterborough Fen* is situated, containing between 6,000 and 7,000 acres. One seventh part of the Level is situated in Huntingdonshire. Nearly the whole of the Isle of Ely, which forms the northern division of Cambridgeshire, consists of this marshy ground. The south-east part of Lincolnshire, usually named *Holland*, extending to the river Witham on the north, is a fenny district, included in the Bedford Level. 63,000 acres are situated in Norfolk, and 30,000 in Suffolk.

There is sufficient evidence to prove that at a much lower level than the present surface, the Bedford Level was formerly dry land. From natural convulsions, and, at a later period, from embankments improperly made, the waters from the uplands were prevented from flowing into channels through which they might discharge themselves into the sea; the consequence was that the tract became gradually reduced to the state of a morass, where the waters stagnating and becoming putrid produced miasma injurious to the inhabitants; while from the sedge, reed, and slime which covered this extensive district, it became impassable even to boats. At the time of the invasion of the Romans this Level was, probably, one of those vast forests to which the Britons fled for protection against their invaders, whose policy it was to cut down the trees, and thus destroy these native retreats. When the Romans became masters of the island they compelled the Britons to clear the woods, and embank the fens. The Roman emperor Severus, who died at the commencement of the third century, was the first who intersected these fens with causeways. One of these, extending from Denver, in Norfolk, to Peterborough, was 24 miles long, 60 feet broad, and composed of gravel 3 feet in depth. This causeway is now covered with moor from 3 to 5 feet in thickness. At that early period this low land, though damp, was not impassable; but up to the 13th century, it appears that the waters usually flowed in natural channels, and had not devastated the surrounding country. But in the year 1236, on the morrow after Martinmas day, and for the eight succeeding days, the sea was raised by a strong wind higher than its usual bounds, and it broke in at Wisbeach and other places, destroying many people, cattle, &c. A similar accident occurred 17 years after, and the king ordered the inhabitants to repair the banks: this does not appear to have been done very efficiently, for a few years after, they were again broken by the violence of the tides.

In the course of draining this district, abundant evidence was found of the previous vegetation, and that it was inhabited before the sudden catastrophe which overwhelmed it. "Oak trees were frequently found at a depth of 3 feet or more beneath the surface, lying near their roots, which still stand as they grew in the firm earth below the moor, and the bodies for the most part north-west from the roots, not cut down with axes, but burnt asunder somewhat near the ground. Some of these trees are 5 yards in circumference, and 16 in length, and many have acorns remaining near them. There are also fir-trees, which lie 1 foot or 18 inches deeper, many of them are more than 30 yards in length," and, according to Dugdale, one was taken out in the year 1653, "36 yards long without the top, which was lying near the root, which stood likewise as it grew, having been burnt, and not hewn down, which tree bore at the bottom 10 inches square, and at the top 8." A ladder of fir with about 40 staves, 33 inches asunder, was found in the moors at Thurne, and at Haxey-Carr, a hedge with stakes and binders. Dugdale states that the buried trees are so numerous that the inhabitants have on an average taken up 2,000 cart-loads in a year. In making a deeper channel to the Wisbeach river, 8 feet below the then bottom, another hard, strong bottom was found, on which were lying 7 boats covered with silt. In digging through the moor at Whittlesey, in the Isle of Ely, for the purpose of making a moat, at the depth of 8 feet a perfect soil was found, with swaths of grass lying on it as they were first mowed. At Shirbeck Sluice, near Boston, a smith's forge was discovered buried 16 feet deep; the remains of several ancient tan vats were also found, besides a great quantity of horns, and some shoe soles, sharp-pointed in the fashion of those worn in the reign of Richard II.

In 1436 the project of draining these fens engaged attention. Large sums of money were expended in making the ditches and banks secure, but the next winter being wet and windy, the river Ouse, swelled into a torrent by tributary brooks, swept away all the bulwarks opposed to it. This accident long delayed the execution of the great project, which, however, was constantly being discussed by persons who favoured as well as by those who opposed the undertaking. It was not till the year 1634 that William, Earl of Bedford, undertook to drain this fenny district, (hence called the *Bedford Level,*) on condition that 95,000 acres of the reclaimed land should be allotted to him as a compensation for the expense and trouble incurred. In the course of 3 years 100,000*l.* were expended in the attempt, and the work was partially accomplished; the embankments, however, proved defective, and the whole was again allowed to lay waste until 1649, when the Earl once more attempted the task. 300,000*l.* were then expended in draining, embanking, &c., and the work was successful, as far as the reclaiming of the land was concerned, but the sharers in the undertaking found that the 95,000 acres were of much less value than the sum expended in procuring them From this time, however, a regular system was adopted for draining and preserving the land already reclaimed. In 1664 a company was incorporated for its management, consisting of 1 governor, 6 bailiffs, and 20 conservators; and to the present day the fens are managed and preserved by this corporation. Numerous cuts have been made, intersecting every part: some of these cuts are so large and deep as to serve for navigable canals. In the Isle of Ely the Old and New Bedford Rivers are two cuts running nearly parallel to each other, both navigable for upwards of 20 miles, from Erith to Denver. In draining the marshes the water is raised to the proper channel by machinery moved by windmills. In some cases these mills turn a kind of perpetual screw, made of wood several feet in diameter, mounted on a solid axle. This screw fits a semicircular trough, inclined at an angle of about 30° the lower part of which dips into the water below, and by its revolution discharges the water into a reservoir above. In this way the friction of pumps, and the wearing out of machinery is avoided. The mills require but little attendance, and work night and day whenever the wind blows.

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[1] "On the Drainage of Districts and Lands," by G. D. Dempsey, C.E. 1849. Published in Weale's "Rudimentary Series." This valuable little work has been of considerable assistance in preparing this article.

Numerous projects have been adopted to complete and secure the drainage of the fens; and a vast expense has been incurred, sometimes much greater than the value of the land reclaimed. "In Huntingdonshire, about the latter end of the last century, the tax raised on the land by the conservators, for its drainage, and the preserving of its embankments, was in some instances so great, that the farmers preferred forfeiting their land rather than paying so exorbitantly for its preservation. In the present day the art of drainage is better understood than when first this stupendous work was undertaken; but even now, in many places, the farmer is still liable to have the produce of his grounds carried away by sudden inundations. The peculiar situation of the Level renders it the receiver of the waters of nine counties, and, therefore, it is difficult to provide a sufficient outlet to the sea by which the descending torrent may find a safe egress. The great error committed in the commencement of the drainage was the making numerous small cuts instead of larger and deeper channels, by which, with the same inclination of descent, the water would safely pour into the sea, without any risk of overflowing its banks; since in a narrow and shallow channel, owing to the smaller force exercised by the lesser body of water, the bottom must be made at a much greater inclination to cause the free flowing of the stream." Large and deep rivers run sufficiently swift with a fall of about 1 foot per mile, or 1 in 5,000. Smaller rivers and brooks require a fall of 2 feet per mile, or 1 in 2,500. Small brooks hardly keep an open course under 4 feet per mile, or 1 in 1,200, while ditches and covered drains require at least 8 feet per mile, or 1 in 600. Furrows of ridges and filled drains require much more.

We now proceed to give a few illustrations of the art of draining, taking in the first place the example of a level district with high land behind it. In draining this such an arrangement is made as is shown in Fig. 726, in which A B is the river, and C D the high land. E F G represent what is called a *catch water* drain, for receiving the waters from the high land. H I J, a parallel main drain for the level with another main drain, I K. Between the main drains the level is intersected with minor drains, which have a fall either way towards the mains. The catch-water drain is adapted to discharge directly into the river; or, by closed sluices at E G, and an open one at F, its contents may be directed into the main level at I, and made to assist the irrigation of the level in dry seasons. Sluices will be required at E, F, G, H, I, J, and K, by the regulation of which the water may be collected and disposed of as required. The drains required for such works must be of large size. Drains of the sections shown in the following figures, with a fall of 18 inches per mile, will discharge as follows:—Fig. 727, 10-feet drain, will discharge 1193.4 cubic feet per minute Fig. 728, 15-feet drain, 2,880 cubic feet per minute; and Fig. 729, 18-feet drain, will discharge 4,642 cubic feet per minute. Fig. 730 is a section for an embankment against the sea for works of this kind. E, the embankment of earth; W, a solid wall or dyke of puddle; M, a facing wall of masonry, S, high-water level of the sea or bay, and B, the natural

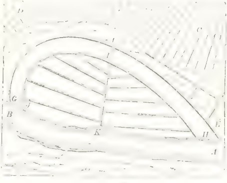

Fig. 726.

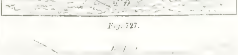

Fig. 727.

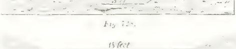

Fig. 728.

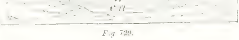

Fig. 729.

bed. The front wall is formed so as to resist the action of the waves, and the internal slope of the embankment must be adapted to the nature of the materials of which it is composed.

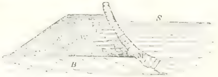

Fig. 730

The waters both of the high and of the low lands being thus discharged into the river, it is of great importance that the channel of the river be of sufficient dimensions, and of the proper form to maintain an active and sufficient current through it, for which purpose there must be a direct course, and a sufficient fall for the channel. "If the direction be tortuous, the projecting banks will be washed into the bed, and impede the flow of the current, and if the bed be on a dead level, or have an inadequate inclination, the flow will be sluggish, and lend no assistance to the discharge. Besides these conditions, it is necessary that the outfall of the river into the sea be of ample dimensions, and unencumbered with shoals, bars, or other solid accumulations." [See DREDGING.] If the outfall be unimpeded, 4 or 5 inches per mile will be a sufficient fall, but if the channel be obstructed by old bridges, bendings, &c., as much as from 12 to 18 inches per mile will be required.

As important works of this kind, Mr. Dempsey instances those for improving the rivers Ouse and Nene. The chief defect in the former existed above the town of Lynn, where the river turned almost at right angles to its general course, and in a length of 5½ miles formed a semicircle of only 2¾ miles in diameter. The channel was also so irregular in width, and encumbered with shifting sands, that the tidal and drainage waters were unable to force a passage, and disastrous inundations were the result. In 1724, the proper remedy was proposed, viz. by making a direct cut, which should intercept the bend; but it was not till 1817 that an Act was obtained for executing this important work, which was named the Eau Brink Cut. The late Mr. Rennie was the engineer. The works were finished on the 19th July, 1821, and their effects have proved highly successful: they have lowered the low-water line in the river several feet, and have completed the drainage of upwards of 300,000 acres of land. A similar work was executed in 1829 by Telford and Rennie, at the outfall of the river Nene, which commences about five miles below Wisbeach, and terminates after a length of five miles in the great estuary of the Wash. The effects of this improvement have been to lower the low-water mark 10½ feet, and to bring a district of upwards of 100,000 acres, which was a stagnant marsh, into cultivation.

Connected with the drainage of low lands are the operations by which land is reclaimed from the action of the sea. The alluvial matters brought down with the drainage waters and thrown back by the tide, are collected into embankments for the purpose of restraining the advance of the waters. Embankments are also required in districts which lie below the level of the adjacent river, or so little above it that the beds of drains are below the water-line. Artificial means are then resorted to for discharging the drainage waters into the receiving channel or river. For example, in Fig. 731, L represents the general level of the district, D that of the water in the drain to be discharged, E the top of the embankment, and H the high-water level outside. In order to transfer the contents of the drain D into the main channel H, such machinery is erected on the embankment as will bring the water up on one side and discharge it on the other. The Dutch, who carry on this method of draining extensively in their low lands, employ scoop-wheels worked by means of windmills, as already noticed. Mr. W. Fairbairn, however, has contrived a new form of scoop or alternating trough, adapted to be worked by the single-acting Cornish engine. The bail-scoop S, Fig. 732, turns on a centre at C, fixed on the embankment E: the other end of the scoop is connected at R by a connecting-rod with the end of the engine-beam B, of which *c* is the centre, and erected on suitable foundations, F. L is the level of water in the river, and D the drain from which the water is to be discharged. The engine is of the reciprocating kind, and by raising a weight suspended at the other end of the engine-beam B, the scoop S descends, and becomes filled with the drainage water through the opening valves at *v*. The weight having been raised to the height of the stroke, descends by its own gravity, and raising the end R of the scoop, discharges its contents into the river at L. By shifting the connecting-rod at the two ends the dip may be regulated. The scoop is made of iron boiler-plates, and is 25 feet long and 30 wide, with two partitions across it, to strengthen the sides and afford bearings for the valves at *v*. 17 tons of water can be raised at each stroke by this machine, and with

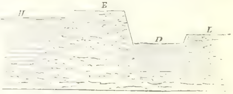

Fig. 731.

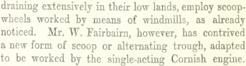

Fig. 732.

an engine of sixty-horse power will do a duty equal to three pounds of coal per horse power per hour.

The application of the steam-engine to drainage is one of the greatest improvements that have been introduced into the arts. In 1820, Mr. Rennie applied one of Watts's engines to the working of a large scoop-wheel, for draining Bottisham Fen, near Ely. Since that time, large districts have been effectually drained by steam power. Such, for example, as Deeping Fen, near Spalding in Lincolnshire, containing 25,000 acres: this was drained by means of two engines, of 80 and 60 horse-power. Littleport Fen, near Ely, containing 28,000 acres, was drained by two engines, of 30 and 40 horse-power, taking the place of 75 wind-engines which were formerly used. Middle Fen, in Cambridgeshire, 7,000 acres, was drained by one engine of 60-horse power. Many other examples could be cited.

"If the drainage from the high lands be discharged through catch-water drains, that from the low levels will consist of the rain-water only; and as this in the fen districts on the eastern side of England seldom exceeds the average of 26 inches in depth per annum, of which a large quantity is carried off by evaporation and absorption, 2 inches in depth, or $1\frac{1}{2}$ cubic feet of water on every square yard of surface, is the ordinary maximum quantity to be lifted per month. Adopting the admitted standard of horse-power, viz. 33,000lbs. raised one foot per minute, and the weight of a cubic foot of water to equal $62\frac{1}{2}$lbs., or 10lbs. per gallon, a horse's power will raise 330 gallons, or 52.8 cubic feet of water 10 feet high per minute. The total quantity to be raised per acre per month, viz. 7,260 cubic feet, may thus be raised a height of 10 feet and discharged in about 2 hours and 10 minutes. Upon this calculation, which Mr. Glyn has found to be supported in practice, it appears that a steam-engine of 10-horse power will raise and throw off the drainage-water due to a district of 1,000 acres of fens, in each month, in 232 hours, or less than 20 days, working 12 hours a-day."

The power of the steam-engine has been nowhere more admirably illustrated than in the drainage of some of those extensive fresh-water lakes, such as the Lake of Haarlem, in Holland, for the purpose of cultivating the site which they occupy. The plan adopted by the Dutch government for draining this lake was that recommended by Messrs. Gibbs and Dean, who proposed to employ three engines of great power. One of the engines which has been erected works 11 pumps simultaneously: the net weight of water lifted is 81.7 tons, and the discharge, 63 tons per stroke. By working the 11 pumps without regard to economy of fuel, it was found that 109 tons of water could be raised per stroke to the height of 10 feet.

In draining the lands of valleys in which natural watercourses, such as rivers, &c., exist, the inclination of the surface towards the stream will indicate the method to be adopted. If the surface be comparatively level, the beds of the drains may be parallel or nearly so to the surface, and arranged to deliver into one or more main drains with lower beds, but still above the low-water level of the receiving channel. If the surface undulate, the main drains must be laid in the hollows, and the feeders be distributed over the high parts and made to communicate with the mains. By means of small sluices fixed at intervals in the main and minor drains, the water may be made to accumulate for the purpose of flooding or irrigating the higher lands. Fig. 733, is a plan, and Fig. 734 a section of a district so arranged. R R′ is the river or receiving channel, D D′ the principal main drain, and *c c′*, *d d′* two other main drains delivering into it; each of the mains receiving the drainage from the feeders or minor drains. The section Fig. 733, is supposed to be taken on the line S S′ on the plan. In such arrangements as these it is necessary that all the junctions be curved, and that no two feeders enter the main drain at opposite points. Unless these precautions be attended to, the currents will be interrupted at those points, and flooding be produced in wet seasons. The junctions should also be guarded with a few rough stones piled together in the form of a retaining wall, or even concreted with lime and gravel.

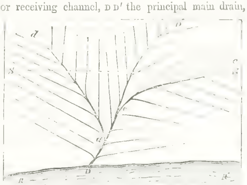

Fig. 733.

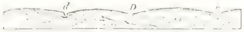

Fig. 734.

When the general inclination of the surface is considerable, it may be desirable to form catch-water drains, or series of drains at different elevations communicating with each lower one in succession by means of falls. In this way the waters are under control, and the falls may even be used as water power.

It was formerly the custom to drain only on very wet and marshy soils; but at the present day it is often had recourse to with the best effects on land that externally appears dry. The fact is that stagnant water frequently exists underneath the surface, injuring the crops and sending up reeds, rushes, or rank grass to betray its presence. Drainage in such a case promotes healthy circulation, and is of the highest importance, as will be seen from the opinions of the competent authorities quoted at the commencement of this article. The simplest kind of drain, as already noticed, is a mere cut or channel in the surface of the ground; but this is useful only to carry off rains and surface waters: the more complete form of under-ground or covered drain conveys away the superabundant moisture from the body of the soil. The Romans were acquainted with both forms of drain, and their earliest agricultural writings give particular directions for making them. In our own country there is no distinct mention of draining until the reign of William the Conqueror, when it is stated that a great extent of country was drained by the king's chamberlain, the Lord of Brunne and Deeping. A book published in the reign of Henry VIII. gives minute directions for draining; but the art was imperfectly known and practised until the close of the last century, when a new system was introduced by a practical farmer named Elkington, and this system has been the foundation of numerous others in practice at the present time. The first idea of Elkington's method is said to have been suggested to him in the following manner:—One of his fields being very wet, so that sheep fed in it became afflicted with the rot, he dug a trench four or five feet deep to discover the cause of the mischief. While he was examining this trench, a servant passed by with a crow-bar for fixing sheep-hurdles in the ground. Elkington took the crow-bar and plunged it into the bottom of the trench, to discover, if possible, what lay beneath. The crow-bar sank deep, and on pulling it up, to his astonishment a great quantity of water welled up through the hole which it made, and flowed along the trench. Thus he discovered that large bodies of water may be pent up beneath the soil, and may be let off by tapping with an auger or rod. Applying his knowledge of this fact with great skill and sagacity, Elkington became famous for his system of drainage, which when compared with the old method was found as much more effectual for the purpose as blood-letting is more effectual on the human constitution than the local application of leeches. By making a few deep drains and boring in the most essential spots, he performed the work much more perfectly than he could have done by numerous conduits near the surface. Although not a scientific man, he was gifted with natural shrewdness and powers of observation which enabled him to detect the seat of springs, a most difficult task, and to apply the proper remedy.

There are three leading varieties of soil to be considered in drainage, for according to their relative position the mode adopted will vary. These are the *porous* soil, the *retentive* soil, and the *mixed* soil, which partakes of the qualities of both. A common arrangement of these is for the porous, P, Fig. 735,

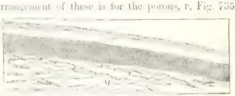

Fig. 735.

to lie immediately beneath the surface, the retentive, R, next, and the mixed, M, lowest. In this case the drains must either be made with regard to the porous soil only, without interference with the retentive or clay, or the main drains must be made completely through the clay, which will bring the land into a much drier condition. Boring in the wettest places may also be resorted to. In other cases, where the clay or retentive soil, R, Fig. 736, is uppermost, and

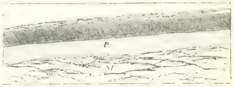

Fig. 736.

the porous soil, P, underneath, it will be imperative to cut the drains entirely through the clay, and if the porous soil be shallow, to cut them through that also. Where the clay bed is too thick to be cut through, numerous small drains must be made, to free the clay as much as possible from excess of moisture. If a tongue of porous soil, I, Fig. 737, lie upon one of

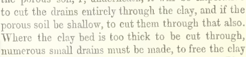

Fig. 737.

clay, no drainage of the former will have any effect, but a main drain, if possible, entirely through the clay at the point marked D, will be the remedy needed. If a similar tongue extend under and amidst the clay, as at P, Fig. 738, there must be not only a drain

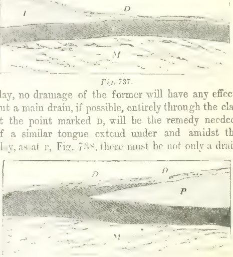

Fig. 738.

through the clay over the tongue, but another at the foot of the tongue also, as at the points D D. So, also, where beds of gravel or other porous material lie in the midst of a retentive bed, two sets of main drains will be, in like manner, required.

Surface drains are sometimes open, and are proportioned in size to the quantity of water they have to carry away. Their sloping sides, however, occasion much loss of soil. The simplest kind of covered drain is a trench two or three feet deep, filled with stones and rubbish to within a foot of the surface. An improvement on this is when the stones are arranged in such a manner as to leave an open conduit at the bottom. This is still better effected when a semi-cylindrical tile is placed on a flat tile, and occupies the lowest part of the drain, as in Fig. 739; or if slate is plentiful, this will be cheaper than the flat tiles, and will answer the same purpose, namely—to prevent the arched tile from pressing into the soil, and so becoming useless. Another form of conduit is shown in Fig. 740. In laying these flat tiles or soles, as they are called, care is taken not to let their joints correspond with those of the drain tile. See Fig. 741. At regular distances, where branch drains are to enter the main, a tile is used for the latter which has an opening in its side, into which the branch drain is exactly fitted. Drain-tiles of a cylindrical form, or of a form embracing that of a sole and tile in one, are now much used. The chief danger is of their slipping apart at the joints and thus spoiling the drain. Sometimes this is provided against by a sort of collar covering the joint; sometimes by making the ends of the cylinders lobed or waved so as to fit into each other. See Fig. 742.

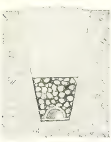
Fig. 739.

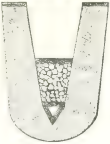
Fig. 740.

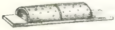
Fig. 741.

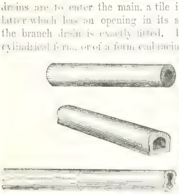
Fig. 742.

In deep draining the processes already noticed are performed on a larger scale. The conduit at the bottom is built securely by a person who understands the construction of dry stone walls, and the drain is filled up with stones, having a layer of turf, coarse grass, or dry leaves over them, before the soil is covered in. Boring is frequently resorted to, and a common auger, a sharp pyramidal punch, and a chisel or jumper are all required. [See BORING.] The three leading points in deep draining in which Elkington's peculiar skill became remarkable were, first, finding out the main spring, or cause of the mischief; secondly, taking the level of that spring, and ascertaining its subterraneous bearings; and, thirdly, making use of the auger to reach or tap the spring, when the depth of the drain was not found sufficient to answer his purpose. Skill of a similar kind to his is required to conduct deep draining with good effect, otherwise great expense may be contracted to little purpose. The tapping of the soil is, of course, only available where the spring is fed from a higher level, so that the pressure may force the water up through the auger-hole. Sometimes, as a substitute for the auger-hole, a well is formed and filled up with loose stones, through which the water rises and passes along the drain. Similar wells are sometimes formed for the opposite purpose of conveying the water from surface drains through a retentive soil into a more porous one beneath. The varieties in draining are, indeed, almost endless, and the locality to be operated upon should be closely studied before the precise mode of working be decided on. Surface drains must be placed lower than the plough will penetrate, or they will be constantly liable to disturbance. In forest land drains must be open, for covered ones are soon rendered inefficient by the roots of trees penetrating and choking them. The dimensions and distance apart of the several drains must be determined entirely by the nature of the soil, and the amount of water to be carried off. An average scale for determining these points has been drawn from experience on various soils, and is given as follows in Mr. Dempsey's treatise:—

CHARACTER OF SOILS	DRAINS	
	Depth	Distance apart
COMPACT.	Ft. In.	Ft.
Tenacious clay	2 6	15
Friable clay	2 9	18
Soft loamy clay	2 9	21
MEDIUM.		
Clayey loam	3 0	21
Gravelly loam	3 3	27
Friable loam	3 3	30
POROUS.		
Light loam	3 6	33
Sandy loam	3 9	39
Light gravelly sand	4 0	51
Coarse gravelly sand	4 6	60

The cost is also estimated as follows:—

No.	Soils.	Depth of Drains.	Distance between the Drains.	Cost of Labour per Acre.	Cost of Pipes or Tiles per Acre.	Total Cost per Acre.
		Feet.	Feet.	£ s. d.	£ s. d.	£ s. d.
1	Clay	—	15	11 4	3 0 11	5 12 3½
2	Sandy clay	—	18	2 2 1	2 10 9¾	4 13 8½
3	Ditto	—	21	1 16 9	2 3 6	4 0 3½
4.	Free stony subsoil	—	24	1 12 1	1 18 1½	3 10 2½
5	Ditto	—	27	1 8 7	1 13 10¼	3 2 5¼
6	Porous	—	30	1 5 8	1 10 6	2 16 2
7.	Ditto	—	33	1 3 4	1 7 8½	2 11 0½
8	Sand or gravel	—	36	1 1 7	1 5 4	2 6 11
9.	Uniform clay	3	33	1 0 0	7 11	1 7 11
10.	Ditto	3	33	1 0 0	7 11	1 7 11
11	Ditto	3 to 4	33	1 6 8	7 11	1 14 7
12	Ditto	3½ to 4	40	1 2 0	6 6	1 8 6
13.	Clay, with some stones	4	70	1 6 6	5 3	1 11 9
14.	Clay, hard gravelly subsoil	3 to 3½	42	1 15 6	5 4	2 0 10
15	Ditto	4	30	1 15 6	5 4	2 0 10
16	Various clay, gravel, sand	4	66	1 6 8	4 0	1 10 8
17	Clay, gravel, sand	3½ to 4	33	2 10 0	7 11	2 17 11
18	Heavy clay	4	36	—	—	4 11 7
19.	Various clay	4	36	—	—	3 15 5
20.	Strong clay	4	20 to 25	—	—	4 1 2
21	Strong land	4	24	—	—	4 15 7
22	Weak blue clay	4	30	—	—	4 13 11
23	Whitish stubborn clay	4	30	—	—	4 1 1
24	Strong clay and gravel	4	33 to 50	—	—	5 3 4
25.	Whitish clay	4	[illegible]	—	—	4 4 8

The drainage of houses and towns will be noticed under the article SEWER.

DREDGING, an operation for loosening and lifting the mud, gravel, sand, clay, stones, &c., which are deposited, or may have formed the original stratum of the bed of canals, rivers, docks, harbours, &c.

"If the universal tendency to waste and decay in the higher lands, from the agency of moisture, heat and frost, be considered, we shall find that every rill of water must carry along with it a portion of separated matter. These rivulets being so many tributary streams to the great rivers, which form the drainage of vast tracts of country, we need not be surprised to find that the beds and embouchures of the Scheldt, the Meuse, the Rhine, and the Elbe, or of the Thames, the Humber, the Tay, and other great tributaries to the German Ocean, should be variously silted up; and that even this great basin itself should be much encumbered by numerous banks of deposited matters. To the agency of these, combined with the effects of cross-running tides, we ascribe the existence of the Dogger Banks, the Yarmouth Sands, the Flemish Banks, and even the great platforms of Holland, and the opposite planes of the Fens of Lincoln. There is also a marked difference to be noticed in the separation and distribution of these matters of deposition. In those rivers which flow with a very gentle current toward the sea, fine silt, or what is sometimes termed *ouse*, is produced; while rivers of greater fall, and consequently of more velocity, carry forward the grosser particles proportionally further from their embouchures. Another circumstance which deserves our notice is the greater specific gravity of salt-water than fresh, which preserves their course in distinct films, the salt-water under the fresh. The salt-water thus flows up the courses of the respective rivers to an extent corresponding to the fall of their beds and the rise of the tide. A considerable portion of the heavier matters, as gravel and sand, are arrested in their progress seaward when the current is languid; while the lighter particles, floating at or near the surface, are either borne along with the stream into the expanse of the ocean, or settle in the eddy waters. In this way the projecting obstacles along the margin are formed, and thus accumulate in the form of sand-banks and small islets; the creeks and sinuosities are also silted up, and too often render the connecting harbours and shipping places so shallow, as to be unfit for the purposes of floating ships of burden. To such a degree has this been experienced in some situations, as for example, Sandwich in Kent, that this ancient sea-port is left almost in the state of an inland town; while other ports have been more or less deteriorated."[1]

The various methods of dredging may be arranged into two great classes, the natural and the artificial, the former of course being preferred where circumstances admit of it. The great natural agents in dredging are the drainage waters of the connecting district, and the flow of tidal waters, the former being judiciously applied, and the latter preserved in full and ample flow. For example: at Montrose, in Forfarshire, some of the proprietors have from time to time proposed to make firm ground of the great natural basin connected with the harbour of that port. This basin is flooded every tide to the extent of about 5 square miles, and is estimated, especially in spring tides, to contain about 55,000,000 of cubic yards of the back waters of the tide, which passing 4 times in the 24 hours through this harbour, produced so powerful a current, that the shifting sand-bank at the entrance, called the *Annet*, is prevented from being thrown across the mouth of it in gales of easterly wind. In this state of weather, the Annet-bank has a continual tendency westward, while the back-waters of this great natural basin check its progress, and not only keep the navigation open, but are sufficient to preserve a considerable depth in it during the lowest tides.

Such powerful and valuable means of keeping open ports and harbours are often entirely destroyed by the desire of acquiring land, which leads to the erection of embankments, whereby the back waters arising from the flow of the tide are shut out. The importance, however, of such means has long been recognised by engineers, who in their designs of tide-harbours often introduce scouring basins, as at Ramsgate, Dover, &c. At the latter place this plan is so successful that the entrance to the harbour, which has been quite shut up, has been cleared, and rendered accessible to packets in the course of a few hours. In some cases drainage-water has been kept back by gates, and used as a back-water to scour and keep open the entrance of harbours on our eastern coast, which are very liable to be choked up in stormy weather from the action of the sea upon the sand-banks which encumber the coast. In extensive plans of docks, use is made of a system of sluices for scouring and floating away the mud.

Dredging by artificial means seems to have been first practised by the Dutch for clearing the bars or entrances to their harbours and navigable canals. The first machines employed merely loosened, but did not raise the stuff, a scouring being afterwards effected by means of sluices. These machines consisted of large bars or prongs placed vertically in a frame, and being fastened to a barge placed in the line of the sluices, the whole was impelled forward by the current, thereby scouring the bed. Such a machine, called a *hedgehog*, is still used in Lincolnshire.

One of the earliest dredging machines employed in Britain, consisted of a large plate of iron about 4 feet long and 18 inches deep, sharpened on the under edge. To each end of this plate was attached a plank of hard wood, the sharpened edge of iron projecting about 4 inches below the wooden sides, and a bar of iron supported the other two ends of the wood, and kept them stretched. The machine was something like a box without top or bottom, 18 inches deep at one end, and 10 inches at the other. From the two extreme points of the wood was fixed a chain for attaching the principal working rope or chain. By drawing this machine across the river by means of a capstan or windlass, it becomes filled, and the men shovel out the stuff on the bank. The operation of this machine is slow and tedious, and it is seldom used except in levelling foundations under water when the material is soft; but by forming the mouth of the dredge of curved bars of iron, gravel and stones can be dredged out.

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[1] Encyclopædia Britannica, article, *Dredging*.

For some years the convicts at Woolwich were employed in deepening the river Thames, and obtaining stuff for ballast, or for embankments, &c. by means of the *bag and spoon*. The spoon is a ring of malleable iron 2 feet wide and 2 feet 4 inches deep, sharpened and steeled on the under side for about one-third of its circumference, and pierced on the inner edge with holes for the lacings of the bag. On the upper side a hose is welded for receiving the pole or handle, and from each side about halfway up the spoon is fastened a chain 2½ feet long. These chains meet in a small ring in the middle. The bag is usually of leather, tapering to the depth of about 3½ feet. It is laced to the spoon with leather thongs, and perforated to allow the water to escape. The spoon is worked from the deck of a flat barge or lighter, mounted with a small projecting crane work. A rail is also placed to assist the spoon leader. A snatch-block is also used at the end of the barge away from the crane. It is fixed at the end of the barge, and the rope passing through it is attached to the bottom of the bag.

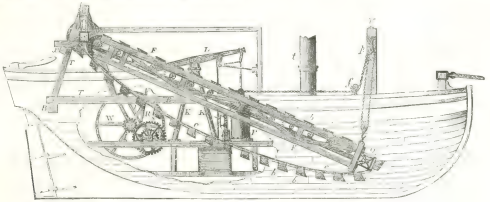

Fig. 743. ELEVATION AND PARTIAL SECTION OF DREDGING MACHINE.

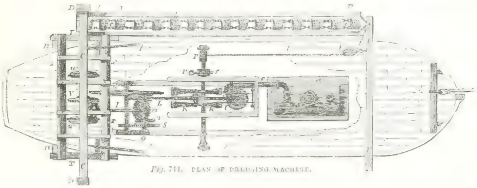

Fig. 744. PLAN OF DREDGING MACHINE.

The working-rope being fastened to the chain of the spoon, and the other end to the barrel of the crane, the man who is stationed at the handle or pole tumbles the spoon into the water. The man at the crane throws it out of gear, when the third man seizes the small rope, which is reeved through the snatch-block, and fastened to the bottom of the bag, with which he runs along the gunwale, and prevents the spoon and bag from sinking until it gets near the other end of the barge, when the man at the pole turns it up, inclining the pole head towards the crane-end of the barge, takes a turn with a small rope round the pole and rail, which keeps the spoon dredging along in its proper position, while the man at the crane draws along the spoon until it is nearly under the crane, when the man at the pole inclines it backwards, and the contents, now deposited in the bag, are hoisted up and emptied into the barge.

As all rivers, harbours and canals, have a tendency, greater or less, to fill up, it is of the first importance in a commercial country like Britain, to have dredging machines of great power to preserve them open. Such a machine is shown in Figs. 743, 744. Fig. 743 is an elevation and partial section of the machine, showing the steam-engine, and wheel-work within the vessel. Fig. 744 is a horizontal plan. This machine, which is erected in the hulk of an old sloop, has two chains of buckets, one on each side of the vessel, but only one of them is shown in Fig. 744. These endless chains revolve on rollers, placed at the two extremities of strong frames of timber F F, which rise and fall on a centre at their upper ends, their weight being suspended by pulleys *p p*, which being lowered down, allow the buckets *b b*, attached to the chain *c c*, to reach the bottom. B B are two beams projecting a short distance from the sides of the vessel at the stern, upon which are mounted two triangular frames T T, for sustaining a strong timber C, extended across the vessel: these with their cross timbers X X form a frame, which supports all the machinery above deck. The beam C is as long as the whole width of the machine, and at each end of it is a cast-iron bracket D D, hanging downwards, for supporting the upper end of the bucket frames F F, and also the centres for the chain-barrels over which the endless chains revolve by the motion of the machine. The bucket frames F F are each composed of 4 long timbers, bolted together, and braced by diagonal stays *s s*. The pulleys *p p*, suspending the lower end of the chain frames, hang from the beam U U, which extends across the vessel, supported on the top of vertical posts erected on the deck. The upper end of each of the chain frames F F has 2 stout iron semicircles *i i* bolted to the timbers and terminating in rings or eyes fitted over two tubes or hollow iron centre-pins, one supported by the bracket D, the other by the frame T. On these pins, the frame hangs as upon a centre at *o*, and can be raised or lowered at pleasure. The upper roller for the endless chain is a square barrel, and revolves upon the same centre *o*, and a similar square barrel of the same dimensions is placed in bearings at the lower end of the bucket frames Q: the double endless chain *c c* passes round both these barrels, and every other link of these two chains carries one of the buckets *b*. Each bucket is made of plate-iron, and is pierced full of holes, to allow the water to drain out of the gravel, as they come up: the mouth is semicircular, which renders it less liable to stick fast in the ground, than if it was square. A number of iron-rollers *r r*, are placed on the inside of the beams of the chain frame, to support the weight of the chains and buckets, as they pass up. The upper chain barrels for the frames on both sides of the vessel, are in a line with each other, and both receive their motion from the steam-engine which is situated in the hold. *a* is the boiler set in brick-work, with the fire beneath it, and a wrought-iron tube *t*, carried up to the proper height, is the chimney: *e* is the steam-pipe communicating from the boiler to the engine: P is the cylinder, L the working beam or great lever, the centre of which is supported by 4 iron columns K K. The connecting rod R of the engine is jointed to the extremity of the beam L, at the top, and at the other end to the crank on the extremity of the shaft O. The fly-wheel W of the engine is turned by the large spare-wheel S, fixed upon the shaft O, acting in a pinion on the axis of the fly-wheel. The motion is conveyed from the engine to the chain barrels, by an inclined shaft T, the lower end of which has a bevelled wheel *m*, receiving motion from the wheel *n*, fixed on the main shaft of the engine. At the upper end of the same inclined shaft is a bevelled wheel V, working another, V′, fixed upon a shaft, situated in a line with the centre of the two chain barrels. At the two extremities of this shaft, two circular iron plates or wheels are fixed at *w w*: these are received into boxes or hollow wheels attached to the extremities of two other shafts placed in a line with the former, and leading to the chain barrels. These boxes and wheels form a connexion between the several parts of the shaft, and by the friction of the wheels, which are accurately fitted to the boxes, a sufficient power is communicated to turn the chain barrels round, and bring up the gravel; but should the buckets take too deep a hold in the ground, these boxes will slip, and thus prevent the chain from being broken. *l l* are levers which operate on coupling boxes on the main horizontal shaft, and give the means of disuniting either of the chain-barrels at pleasure, while the other continues at work. The blocks of the pulleys *p p*, which suspend the great bucket frames, are reeved with a chain, the fall of which passes through the match-block *s*, fixed down upon the deck, and then winds round the roller *z′*. This is turned by the engine, its axis having a worm-wheel *t* fixed upon it, turned by the worm *v*, and shown on a larger scale in Fig. 745. This worm is formed upon the inclined spindle I, but is represented here to avoid confusion.

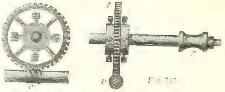

Fig. 745.

The vessel containing this machine is moored in the stream by the head or stern, or both if it be required to work across the stream. The engine being put in motion, the chain frames are lowered down by giving out the chains of the pulleys *p p*, until the buckets drag sufficiently upon the bottom to become filled with ballast in their passage, and come up along the top of the frames by the motion of the chains, till they turn over the upper chain barrels and discharge their contents into large hoppers or troughs, suspended by ropes from the beams T T and C, and being placed somewhat inclined, the troughs conduct the gravel into barges moored beneath. The motion of each chain is managed by one man, who stands near the end of a long lever which supports the pivots of the worm-wheel *t*, so that by moving the end of this lever, the wheel can be disengaged from the worm to give it motion or set it at rest. There is also a gripe or brake wheel, not shown in the figures, fixed upon the spindle of the roller *z′*, to prevent the roller running back by the weight of the chain frames when the wheel *t* is disengaged from the worm. The wheel *t* is attached to its spindle by friction only, so that it can slip if overstrained without breaking the teeth; but it is furnished with adjusting screws, Fig. 745, to give sufficient friction to raise the required load without slipping.

By means of the levers the attendant can cause the buckets to go as deep as may be desirable and as they deepen the channel he gradually raises the gripe-lever, which allows the frame to descend lower down: but if the buckets meet with an obstacle, or take such deep hold as to stick fast, he engages the wheel *t* with the worm by means of the lever, and this winds up the chain of the pulleys *p p*, till the end of the frame is raised sufficiently high from the bottom to disengage the buckets, which then resume their motion, and the wheel *t* is then immediately cast off from the worm, because it is not necessary to raise the frame higher: by relieving the brake-lever it can be again lowered to reach the bottom. There are two other rollers similar to *t*, placed just above the deck, and kept in slow motion by the engine for the purpose of advancing the engine along in the water. A strong rope attached to a mooring block or anchor placed at some distance up the stream, is passed round the roller: a man *holds on* the end of the rope as in a capstan, and thus the whole engine is slowly brought up as the channel is dredged and advanced to operate on a fresh portion of the bed. The above machine working at a moderate depth with an engine of 16-horse power, will bring up enough in an hour to load two barges of 35 tons each. The bucket frame works best at an angle of about 45°; machines of this kind may be used for bringing up sand, mud, clay, gravel, and even stones of considerable size.

In the Humber Dock at Hull, the quantity of mud annually deposited is said to have amounted to 36,000 tons. By means of a dredging machine with 29 buckets, as much as 60 tons per hour can be raised. An engine man and three assistants are required to manage this machine, and two others to attend the lighters. There are 12 boats of 500 tons each employed, and the ordinary work performed is about 45 tons per hour.

DRILLING. In metal works it is frequently necessary to drill holes of various sizes, and with a greater or less degree of accuracy. The methods of drilling are very numerous, as are the forms and sizes of drills used for the purpose. Drills for piercing metal are not, however, so varied in form as those used for piercing wood, [See AUGER;] they are mostly pointed, and first make conical holes, so that while the point of the drill pursues the original line, it at length produces a cylindrical hole. Drills used with the drill-bow do not make holes exceeding $\frac{1}{4}$ inch in diameter: the edges of these drills cut when moved in either direction by the reciprocating motion of the drill-bow, their cutting edges being situated on the line of the axis, and chamfered on each side; hence they cut or scrape equally well in both directions of motion. Fig. 746, is the ordinary double-cutting drill, in which the two facets forming each edge meet at an angle of about 50° to 70°, and the two edges forming the point, meet at about 80° to 100°. The watchmakers, however, sometimes make the end of this drill as obtuse as an angle of about 120°, the object being to prevent the point from protruding through thin works much before the completion of the hole. Fig. 747, is a drill with two circular chamfers; this bores cast-iron, and even wrought-iron and steel, more rapidly than any other reciprocating drill, but a hole must be first made for it with a pointed drill. Fig. 748, is the flat-ended drill used for flattening the bottoms of holes. Fig. 749, is a square countersink drill used for inlaying the heads of screws: it is made cylindrical, and pierced for the reception of a small central pin, and afterwards sharpened to a chisel edge as in the figure. The pin may be enlarged by having circular collars fitted on it, or such collars may be fitted on the larger part to serve as a stop in inlaying. The cutler's duplex expanding drill, Fig. 750, is described under CUTLERY.

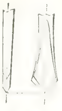
Fig 746.

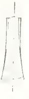
Fig. 747.

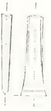
Fig 748.

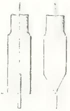
Fig. 749.

Drills which cut only in one direction are shown in the following figures. Fig. 751, is the common single-cutting drill for the drill-bow, brace, and lathe. The point is nearly a rectangle formed by only two facets, which meet the sides at about 80° to 85°, and therefore lie nearly in contact with the extremity of the hole operated on. Turning tools for brass are formed in this way. Fig 752, is a drill suitable for horn, and substances liable to clog the drill; the chamfers are rather more acute and are continued around the edge behind the largest diameter, so that the drill can cut its way out of the hole. The single chamfered drill, Fig 751, cuts more quickly than the double chamfered, Fig. 752, but the former is more liable to swerve or run from its intended position. "In using the double cutting drills, it is also necessary to drill the holes at once to their full sizes, as otherwise the thin edges of these tools stick abruptly into the metal, and are liable to produce jagged and groovy surfaces which destroy the circularity of the holes: the necessity for drilling the entire hole at once, joined to the feebleness of the drill-bow, limits the size of these drills." In using the single chamfered drills, it is desirable to make large holes by a series of two or more drills; "first, the rim of the drill is in a measure proportioned to its diameter, therefore the small tool departs less from its intended path, and a central hole once obtained, it is followed

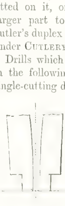
Fig 750.

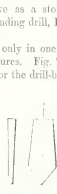
Fig 751.

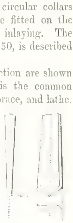
Fig 752.

with very little after risk by the single cutting-drill, which is less penetrative. This mode likewise throws out of action the less favourable part of the drill near the point, and which in large drills is necessarily thick and obtuse: the subdivision of the work enables a comparatively small power to be used for drilling large holes, and also presents the choice of the velocity best suited to each progressive diameter operated upon."[1] Where sufficient power can be obtained, it is desirable to enlarge the holes previously made with the pointed drills by some kind of pin-drill, such as Fig. 753, in which the guide principle is employed very perfectly. Such a drill as this is used for cutting out large holes in cast-iron and other plates: the narrow cutter removes a ring of metal, which is less laborious than cutting the whole into shavings. Fig. 754, is the ordinary pin-drill used for making countersinks for the heads of screw bolts inlaid flush with the surface. When this drill is used for iron, it is fluted: the form of one of the edges is shown at *a*.

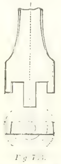

Fig. 753.

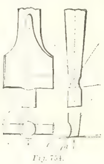

Fig. 754.

The drills are assisted by some lubricating fluid, such as oil for most metals, or, for greater economy, soap and water; milk is used for copper, gold, and silver; but cast-iron and brass are usually drilled without lubrication. Common pointed steel drills are commonly used for the above metals and for alloys of similar degrees of hardness; but for lead and very soft alloys, carpenters' spoon bits and nose bits [See Auger] are commonly used with water. For hardened steel and hard crystalline substances, copper or soft iron drills supplied with emery powder and oil are used; or diamond drill points [See Carbon, Fig. 465,] are used for hardened steel with oil alone. For various forms of tools used for mineral substances, see Boring.

The drill used in watch work is the smallest: it is made of a piece of steel wire tapered off at one end, flattened with the hammer and filed up in the form shown in Fig. 755: it is then hardened by heating it in the flame of a candle, and cooling it by plunging it into the tallow. The reverse end is made into a conical point and hardened: a small brass sheave is attached near this end for the line of the drill bow which may be a fine horse-hair stretched by a piece of whalebone. Fig. 755 is the watchmaker's drill on a large scale. As the drills increase in size the bow is increased also: the bow may be formed of the half of a solid cane about 1 inch in diameter at the larger end, and 30 inches long, or it may be made of steel with a hook at the end for the knot or loop of the cord, and a ferrule or a ratchet, round which the spare cord is wound. The breast-plate used for the short end of the drill is shown in Cutlery, Fig. 707.

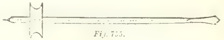

Fig. 755.

To prevent a constant repetition of the shaft and pulley, holders, or *drill-stocks*, are often used, a simple form of which is shown in Fig. 756: it has the centre and pulley of the common drill, but the opposite end is pierced with a hole, at the inner extremity of which is a notch: the shank of the drill is made cylindrical, and a short portion is nicked down so as to slide into the gap in the drill stock, by which the drill is prevented from revolving in the stock.

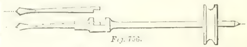

Fig. 756.

The *drilling-lathe* is a miniature lathe-head, the frame of which is fixed in the table vice; the mandrel is pierced for the drills, and has a pulley for the bow, as in Fig. 756, except that it is used as a fixture. Fig. 757 is a common form of drill stock, in which the revolving spindle is fitted in a handle, so that it may be held in any position without the use of a breast-plate; the handle is hollowed out for receiving the drills, and is fluted to allow it to be held firmly.

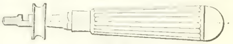

Fig. 757.

The *smith's press-drill* is shown in Fig. 758. It consists of two pairs of wooden standards, between which works the beam *a b*; the pin near *a* is placed at any height, but the weight *w* remains constant, the pressure being regulated by the distance of the brace from the fulcrum *a*, and this part of the beam has an iron plate full of small centre holes for the brace. The weight is raised by the second lever *c d*, the two being united by a chain, and a chain or rope is also suspended from *d* within reach of one or two men who move the brace. When the drill is nearly through

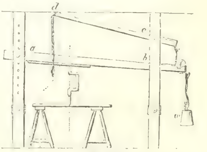

Fig. 758.

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[1] Holtzapffel. "Mechanical Manipulation," vol i. Chapter XXIV. on Boring Tools.

the hole, the weight must be relieved, or it may suddenly break through. The defects of this machine are, that the upper point of the brace moves in an arc instead of a right line; and that there is a necessity of shifting the fulcrum *a*, and for re-adjusting the work under the drill for each different hole.

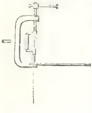

Fig. 759.

Fig. 759 is a portable iron bow frame or clamp, in which the pressure is applied by a screw. In a common form used for boring the sides of water and gas pipes the frame divides into two branches about 2 feet apart, and these terminate like hooks, which loosely embrace the pipe, so that the tool retains its position and may be used by one man; whereas in Fig. 758 one man is required to hold the frame, while another uses the tool.

The more modern form of drilling apparatus is shown in Fig. 760. It consists of a cylindrical bar, *a*, on which the horizontal rod *b* is fitted with a socket capable of being fixed at any height or in any angular position by the set-screw *c*. A socket slides upon *b* capable of being fixed by its set-screw *d* at any distance from *a*; *e* is a long vertical screw, passing through the socket, by which the brace is thrust into the work to be drilled; this is placed level either on the ground, on trestles, on the work bench, or in the vice; the screws *c* and *d* are loosened, and the brace is put in position for work, and examined with a plumb line; the whole is then made fast by the screws *c* and *d*. In some cases the rod *a* is rectangular, and extends from the floor to the ceiling, and traverses in fixed sockets. In Fig. 760 the rod *a* terminates in a cast-iron base, by which it is grasped in a tail-vice, or it may be fixed upon the bench, in which case the nut is unscrewed, and the cast-iron plate *p* when reversed serves as a pedestal, the stem is passed through a hole in the bench, and the nut and washer when screwed on the stem beneath secure all very strongly together.

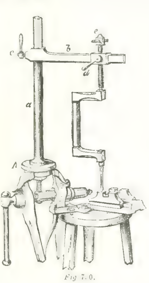

Fig 7.0.

The common brace, shown in Fig. 761, is fitted with a left-hand screw. Mr. Holtzapffel remarks that "various useful drilling tools for engineering works are fitted with left-hand screws, the unwinding of which elongate the tools; so that for these instruments which supply their own pressure, it is only necessary to find a solid support for the centre. They apply very readily in drilling holes within boxes and panels, and the abutment is often similarly provided by projecting parts of the castings; or otherwise the fixed support is derived from the wall or ceiling, by aid of props arranged in the most convenient manner that presents itself. . . A right-hand screw would be unwound in the act of drilling a hole when the brace is moved round in the usual direction, which agrees with the path of a left-hand screw. The cutting motion produces no change in the length of the instrument, and the screw being held at rest for a moment during the revolution, sets in the cut; but towards the last, the feed is discontinued, as the elasticity of the brace and work suffice for the reduced pressure required when the drill is nearly through, and sometimes the screw is unwound still more to reduce it."

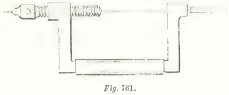

Fig. 761.

A simple addition to the braces and drill tools is a socket, Fig. 762, with a square hole at one end for the drills, and at the other end a square tang to fit the brace. In this way the length of the drill can be extended for reaching deeply seated holes. These sockets are made of various lengths, and in some cases 2 or 3 are used together to extend the length of the brace to suit the position of the prop.

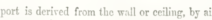

Fig. 762.

The drilling tools now described are driven by hand-power. In some kinds of work, however, they are fixed in square or round hole drill-chucks, which screw upon the lathe mandril. In the manufacture of harps, for example, there is a vast quantity of small drilling which is performed in this way. Various forms of lathe-drills and other forms of hand-drills are described in Mr. Holtzapffel's work, to which we must refer; but we cannot conclude without some notice of drilling machines worked both by hand and by steam-power. Of the former kind is Nasmyth's *Portable Hand-drill*, Figs. 763, 764, in which the spindle is driven by a

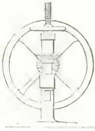

Fig. 763.

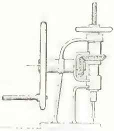

Fig. 764.

pair of bevil pinions, the one attached to the axis of the vertical fly-wheel, the other to the drill-shaft, which is depressed by a screw moved by a small hand-wheel.

Messrs. Whitworth and Co., of Manchester, have constructed a drilling machine, which is one of the most complete tools of the kind ever constructed.[1] Fig. 765 is a vertical section thereof; in the plane of the axis of the driving cone and work-table. A A is a cast-iron framing, upon which the working parts are carried, as also the work-table and its motions. This framing is formed of a single casting, and is fixed by 3 strong bolts upon the sole plate T, which is intended to rest without fastening upon the floor of the workshop. A strong bracket on the upper portion of the main frame carries the outer ends of the cone spindle *b*, and back speed spindle. Upon the spindle *b* is the driving cone B of 3 speeds, the spur-wheel C, and the bevil pinion D. The speed cone B is loose upon the shaft, and communicates motion to it only by means of the spur-wheel C, which is keyed upon the spindle, and to which the cone can be attached by a stud-pin and nut at *c*. This wheel geers with the pinion E, on the same spindle which carries the wheel M; this, in turn, geers with the pinion N, which is fast upon the end of the cone B, but runs loose upon the cone spindle *b*.

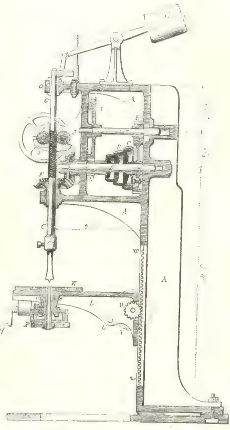

Fig. 765. WHITWORTH'S DRILLING MACHINE.

Supposing the back speed to be removed, the cone being driven by its belt causes the spindle *b* to revolve, because it is attached to the fast-wheel C, and also gives motion directly to the bevil pinion D on the end of the spindle. This again geers with the bevil wheel F on the drill spindle G G, which is free to slide vertically in the eye of the wheel, while it is prevented from revolving in it by a sunk feather. In this way 3 different degrees of quick speed may be given to the drill. But if the back speed be in geer, as in the figure, and the stud-pin *c* removed, and the cone thereby loosened from its attachment with the wheel C, the motion communicated to it will not drive the shaft *b* directly as before, but the pinion N being fast upon it will give motion to the wheel M upon the same spindle with the pinion E. This last will, therefore, make the same number of revolutions as M, but being smaller in diameter will convey a proportionally less velocity to the wheel C, with which it geers, and which it consequently drives with a speed diminished in the ratio of the geering pairs. Now the wheel C being fast on the shaft *b* conveys through it to the bevil pinion D the same diminished speed, and this again to the drill spindle G G. This reduced speed may be varied as before by placing the belt on one pulley or other of the speed cone. Behind the pinion E is a recess to allow it to enter when the back speed wheels are to be thrown out of geer; this speed geer is only required when the machine is boring holes of upwards of 1½ inch diameter. The wheel F is cast with a long hollow boss fitted into a brass collar in the lower branch of the carrying bracket. The drill spindle passes through the wheel F, which thus serves as its lower guide. The upper end of the spindle is guided in a collar similarly fitted into the upper branch of the bracket at *a*. In the figure it is shown at the lowest limit of its travel. A back weight, H, is attached to the top of the drill spindle, by a jointed lever and guide link which embraces the top of the spindle, and moves upon a vertical guide rod kept firm in its place by having its lower end held by a screw nut. The drill spindle is itself screwed towards the middle of its length, where it is embraced by 2 screw wheels, J J, between which it turns, and which serve the purpose of a nut to feed down the spindle in the operation of drilling.

K is the table upon which the article to be bored rests, and to which it can be firmly held down and adjusted by T-headed bolts and glands, the table being recessed and grooved to receive and retain the T-heads of the holding bolts. The table is supported upon the sole of the large bracket L attached to the framing A by two pieces not shown in the figure, bolted upon it and planed true to the angle of the inverted bevil edges of the broad face-rib of the main frame. These edges are also planed where they meet the oblique faces of the pieces, by which means a joint is formed which allows of a sliding motion verti-

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(1) The figure has been copied and the description obtained from Mr David Scott's useful and instructive work, "The Engineer and Machinist's Assistant." 4to. Glasgow, Edinburgh, and London: 1847

cally, but does not admit of lateral deviation. This bracket is raised and depressed by means of a hand crank applied at r. Upon this spindle is fixed the spur-pinion which geers with the spur-wheel v on the same spindle with the pinion w, which geers in turn with the rack *w* set into the frame A. By turning the hand crank on t the bracket can be raised or lowered. The table K has a double movement upon the sole of the carriage bracket: one movement is circular, and the other in the direction of the length of the table. The circular movement is effected by means of the hand crank *p* upon the spindle *y*, Fig. 766, carried in bearings formed on the box X, which thus serves as a centre of rotation. On the spindle *y* is a worm which, geering with the worm wheel r on a stud projecting downwards from the table K, conveys the motion of the handle *p* to the table. The lateral movement is effected by means of a recess in the form of a parallelogram, cast in the sole of the carriage bracket L, with projecting ribs *e e* on its under side, which form guides, against which the cover of the travelling box X slides. Motion is communicated by the handle *q* upon the spindle which carries the bevil wheel o: this spindle has its bearings attached to the bracket L, and its wheel geers with an equal wheel upon the end of the screwed spindle *d*, which has its bearings also attached to the sole plate of the carriage bracket, and works in a long nut or internal screw formed in the cover of the travelling box X. See Fig. 766. By turning the handle *q*, the piece which serves the purpose of a nut on the screw *d* is carried along in the direction of the length of the screw; but the nut being attached to the table K, the whole is moved simultaneously in that direction. By these two motions any point of the table K can be brought under the axis of the drill; and by means of the vertical motion it can be placed at any convenient height.

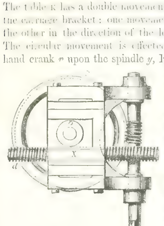

Fig. 766.

The feed of the tool is obtained by means of the two screw wheels J J, on the axis of which are two pulleys embraced on the circumference by friction collars, S S. The bearings of the axis being attached to the framing A, it is evident that the machine being in motion, if the pulleys be prevented from revolving, the wheels J J will also remain at rest; but the screwed part of the drill spindle revolving between them, they will act as a stationary nut, and cause the spindle to descend through a space equal to one thread of its screw during every revolution. If the pulleys and wheels be free, the screw of the spindle, instead of descending, will simply cause the wheels J J to revolve on their axis through a space equal to one tooth during every revolution of the screw. Between these extremes any amount of feed or downward motion of the drill spindle may be obtained simply by retarding the motion of the wheels, by means of the friction collars S S, which embrace the small pulleys on their axis; for the friction of the collars being less than to prevent entirely the motion of the wheels, and at the same time greater than to allow a tooth to pass during a revolution of the spindle, a downward motion of the spindle must thus be produced equal to the retardation of the pulleys produced by the friction collars. The tool can be speedily withdrawn by slacking the friction collars, when the balance weight H will raise the spindle in ordinary cases; and when the tool has a hold in the hole which is being bored, the balance weight can be assisted by the hand wheel placed on the axis of one of the wheels J J: the wheel and screw will thus for the time be converted into a pinion and rack.

DRUGGET, a coarse woollen fabric used for covering carpets.

DRUMMOND LIGHT, see LIME—LIGHTHOUSE.

DRY-ROT, see WOOD.

DUCTILITY, see METAL—WIRE-DRAWING. See also APPENDIX.

DYEING is the art of imparting to wool, silk, cotton, linen, leather, &c., colours which resist the operation of washing and the wear to which they are subject when made up into articles of furniture or clothing. This art was known at a very early period. Jacob made for Joseph a coat of many colours, (Gen. xxxvii. 3;) and in Exodus frequent mention is made of the ornaments for the Tabernacle as being composed of blue, purple, scarlet, and fine linen. We read also in 2 Chron. ii. that Solomon having sent to Tyre for coloured linens, the king of that country answered his request by sending him a man skilful to work "in purple, in blue, and in fine linen, and in crimson." Ezekiel, (593 B.C.) in his prophecy against Tyre (xxvii. 7), speaks of "blue and purple from the isles of *Elishah*," which has been supposed to refer to Elis on the west side of the Greek Peloponnesus, and hence it has been inferred that the Tyrians in the time of Ezekiel drew their supply of shell-fish used for dyeing purple from the coast of Greece. The Tyrian purple was greatly prized among the nations of antiquity. It is supposed to have been obtained from two different kinds of shell-fish, described by Pliny under the names *purpura* and *buccinum;* it was extracted from a small vessel or sac in their throats, one drop only being obtained from each animal, but an inferior colour was obtained by crushing the whole substance of the buccinum. A quantity of the juice having been collected, sea salt was added, and it was allowed to stand three days; after this, it was diluted with five times its bulk of water, kept at a moderate heat for six days more, and occasionally skimmed, and when thus clarified it was used for dyeing white wool previously prepared by the action of lime-water or of a species of lichen. For the finest Tyrian purple, the wool was first plunged into the juice of the purpura, and then into that of the buccinum; by exposure to air and light the wool passed through various shades of citron yellow, green, azure, and red, and after 48 hours a fine purple was produced. In some cases the wool was first dyed with a cheap dye, and the woven cloth was finished with the precious juice. The colours were durable, but very costly: Pliny states that a pound weight of the double dipped Tyrian purple was sold in Rome in the time of Augustus for 100 crowns, (equal to about 30*l.* of our money.)

This enormous price did not prevent many of the citizens of Rome from wearing purple attire until the time of the emperors, when the use of purple was limited to them. This exclusiveness proved fatal to the manufacture: it languished until the eleventh century, and then became extinct. In the seventeenth century the art of dyeing purple was revived by Mr. Cole, of Bristol, and in the eighteenth century by M. Réaumur, of France; but by this time finer colours had been discovered, and cheaper processes invented.

The ancient Greeks do not seem to have attended much to the art of dyeing: the people of Athens wore woollen garments of the natural colour, and although the more luxurious Romans patronised those who cultivated the art, yet the processes of a trade or manufacture were thought to be beneath the notice of any writer capable of describing them. We learn incidentally from Pliny that the competitors in the circus were clothed in dresses of green, orange, grey, and white. The art was lost at Rome after the invasion of the northern barbarians in the fifth century; but it was practised in the East and revived in Europe about the end of the twelfth century. Florence became celebrated in the art, and in the early part of the fourteenth century numbered not less than 200 dyeing establishments.

The discovery of America supplied Europe with a variety of new colouring-matters, such as indigo, logwood, quercitron, Brazil-wood, cochineal, arnotto, &c. Before the introduction of indigo, woad was used for dyeing blue, and the cultivators of this plant in England and on the Continent endeavoured to prevent the use of indigo, which, by a decree of the German Diet in 1577, was declared to be "a pernicious, deceitful, eating, and corrosive dye." The introduction of logwood was opposed from similarly interested motives: its use was prohibited by a statute of Elizabeth, under heavy penalties, and all that which was found in the country was ordered to be destroyed: it was not until the reign of Charles II. that its use was permitted.

Such narrow prejudices as these of course interfered with the progress of the art in this country; but by degrees, valuable improvements were made, and new processes introduced from abroad, such as the method of dyeing Turkey-red,—one of the most durable of colours. It was discovered in India, and afterwards practised in other parts of Asia and in Greece. About the middle of the last century some Greek dyers established dye-works for this colour in France; and in 1765 an account of the method of producing it was published, by order of the French government. About the end of the last century the method was practised in England, when a Turkey-red dye-house was established in Manchester, by a Frenchman, who obtained a grant from Government for the disclosure of his process, which, however, was not very successful. A better process was introduced into Glasgow by a Frenchman named Papillon; but before this, Mr. Wilson of Ainsworth, near Manchester, had obtained the secret from the Greeks of Smyrna, which he made public.

The methods of imparting a permanent colour to textile fabrics are almost as numerous as the colouring matters employed. Most of the colours used in dyeing are vegetable: a few are animal and mineral. The most vivid and brilliant vegetable colours, such as those of flowers and other parts of plants exposed to the light, are small in quantity, very fugitive, and difficult to separate. The colouring matters of plants capable of being isolated, are mostly yellow, brown, and red; the only blue dyes furnished by plants are indigo and litmus; no black vegetable dye has been isolated. Most vegetable colours are soluble in water; and those which are not so can be dissolved in alcohol, ether, or the fixed oils. Vegetable colours are permanent in dry air; but they gradually fade in moist air, especially under the influence of light. The blue of most flowers is converted into red by an acid, and into green by an alkali.

Not only do the methods of dyeing vary with the nature of the dye-stuff, but also with that of the material to be dyed; different methods being adopted for cotton, silk, and wool. In order to convey a general idea of the art, we will refer principally to the dyeing of cotton, which receives colour much less easily than wool and silk, and therefore requires more numerous and elaborate processes.

The appearance of a large dye-house is very interesting from the variety and magnitude of the processes carried on therein. The following general sketch of the Egerton Dye-works at Turton, near Bolton, is quoted from the Editor's work on the "Useful Arts and Manufactures of Great Britain."[1]

"The dye-house at Turton consists of an immense apartment, which forms the basement story of a large cotton-mill. It is paved with stone, and supplied with a complete system of drainage for carrying off the spent dye-stuffs and soiled water which result from each day's operations. On entering this apartment, the visitor is struck with what appears to be the confused assemblage of differently-shaped machines, unlike the sameness which is equally remarkable in the grouping of the machinery of a spinning or weaving-mill. Here are large stone cisterns for bleaching and for washing; dash-wheels, and other wheels, also for washing; vessels containing dye-stuffs, called *dye-becks;* others, containing soap and water, called *soap-becks;* mangles for rolling the cloth; others furnished with brushes for laying the fibres all in one direction; squeezing rollers for pressing out the water from the goods; and a curious

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(1) We have to acknowledge our obligations to this work in the preparation of this article, and also to Mr. Parnell's "Chemistry applied to Manufactures." 8vo. London, 1843.

machine for drying the goods by centrifugal force, which will be noticed hereafter. Under the feet are streams of all colours threading their way through the dregs of other spent dye-stuffs which had been thrown away some time before. Occasionally may be seen a vessel containing a liquid which is boiling without any visible source of heat. Heat, however, is supplied by the introduction of steam from a large boiler in a neighbouring apartment. There are also conveniences for supplying water to almost any amount. In some dye-works the daily consumption amounts to from 600,000 to 800,000 gallons. The purity of the water is of the utmost consequence; distilled or rain-water, or that of an Artesian well, is generally better than spring or river-water, which usually contains lime, and this exerts an injurious action on the dye-stuff: there is also a small quantity of iron in most spring and river-water, which gives a brown tinge to goods washed in them. Adjoining the dye-house is a room for storing, grinding, mixing, and dissolving the various dyeing materials, salts, &c. Infusions of such drugs as fustic, sumach, and logwood are made in tubs or vats; 50 lbs. of the drug being mixed with 200 gallons of boiling water. Some of the vats are furnished with a perforated false bottom, to separate the solid matter from the infusion, and the latter is conveyed to vats in the dye-house. A decoction of sumach is obtained by boiling it in an open copper boiler, which is the vessel usually employed for decoctions. For some delicate dyes, where a steam heat is applied, vessels of tinned iron or copper are used. Different vegetable colouring matters vary so much in their properties, that few general observations apply to all of them. If the substance be very soluble, its solution is usually made in cold water: if only slightly soluble, heat is applied, provided the colour is not injured thereby. When the solution is required to be highly charged with colour, a portion of the water is driven off by heat; but this requires caution, as many vegetable colours are injured by long boiling. If the goods are not kept in constant motion when in the dye-beck, the infusion should be previously filtered, or the clear part poured off, to separate insoluble woody matters. In some cases a coloured infusion is obtained by enclosing the colouring substances in bags, which are removed from the liquid when sufficient colour is imparted. If, however, the goods are kept in continual motion while in the dye-beck, as is almost always done with cottons, the separation of the insoluble matters is immaterial. The vegetable material is commonly introduced in a state of coarse powder into the dye-beck containing cold water: the pieces of cotton are put in at the same time, and the temperature of the liquid gradually increased by the introduction of steam by a pipe connected with the boiler. Motion is given to the goods in the dye-beck by a winch or reel placed horizontally over the middle, so that the cloth may be made to descend into either compartment of the dye-beck by the rotation of the wheel. By another arrangement, shown in Fig. 768, the cloth is wound from one roller to another, passing in the interval through the dye, under a roller placed at the bottom of the dye-beck."

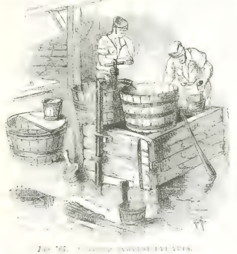


Fig. 767. [illegible]

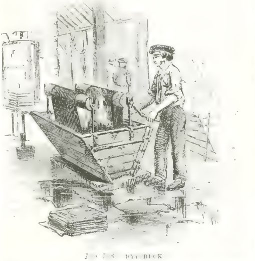
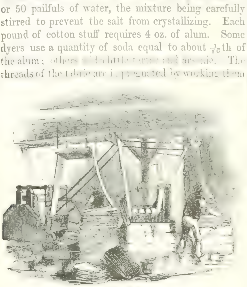


Fig. 768.—Dye-beck.

The fibres of vegetable and animal substances receive colour more readily before they are spun into yarn, and the yarn admits of being more readily dyed than the woven cloth, because the solution of colouring matter has more difficulty in penetrating the twisted than the open fibres. Thus wool in flocks, after having been washed in an alkali and bleached, takes more colour than when it is spun or woven; and the colour of the interior of a piece of thick woollen cloth, dyed in the piece, is often less intense to the eye than the colour of the exterior. Dyeing in the piece is, however, less expensive than dyeing wool in flocks or in yarn, because less of the material is wasted, and the colour is not exposed to injury during the processes of spinning and weaving.

In dyeing cotton goods, several pieces are usually joined together, to make a length of from 100 to 120 yards. Several processes preparatory to the dyeing are required. The goods are first scoured, and in some cases boiled in sour water or in alkaline ley, for about two hours, then wrung out, and rinsed in a stream of water until the water comes off clear. The sour water is prepared by the addition of $\frac{1}{50}$th part of sulphuric acid, and when the stuffs are steeped in it, the acid combines with the calcareous earth and iron contained in the fabric, the presence of which would interfere with the full effect of the colouring matter.

In the dyeing of cotton aluming is an important preliminary process. 40 or 50 lbs. of alum previously dissolved in warm water are mixed in a vat with 40 or 50 pailfuls of water, the mixture being carefully stirred to prevent the salt from crystallizing. Each pound of cotton stuff requires 4 oz. of alum. Some dyers use a quantity of soda equal to about $\frac{1}{10}$th of the alum; others add a little tartar and arsenic. The threads of the fabric are impregnated by working them in small quantities of this solution. After this has been done some time, the whole of the liquor is added, and it is left for 24 hours, after which it is washed in running water for 1½ or 2 hours. Cotton gains by aluming about [illegible]th part of its weight.



[illegible] cisterns.

Galling is another preparatory process. Powdered galls are boiled for two hours in water, the quantity of which must be regulated by the quantity of thread to be galled and the amount of the effect required.

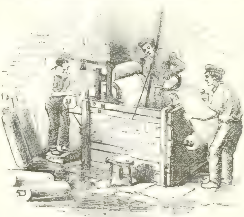


Fig. 77[illegible]

When the solution has cooled down, it is divided into a number of equal parts, in order that the thread may be wrought pound by pound. The whole stuff is then put into a vessel, and the remaining liquid poured upon it. It is left for 24 hours if it is to be dyed black, but for other colours 12 or 15 hours suffice. It is then wrung out and dried.

In passing the goods through these preparing cisterns, the effect desired is produced more effectually and in quicker time, by allowing the cloth to unwind gradually from a roller, and after going through the liquid in a regular manner under a roller at the bottom of the vessel, to pass between two rollers on coming up out of the liquid, whereby the superfluous moisture is pressed out of the cloth and it is again prepared for another dipping. Some idea of the arrangements adopted will be gained from an examination of the Figures.

It is not possible in this short notice to attempt more than to convey a general notion of the chemical principles upon which the art of dyeing depends. In producing certain results, advantage is taken of that affinity or attraction by which one substance A unites with another substance B in preference to a substance C; so that if C be dissolved in A, the addition of B would cause C to leave A in order to unite with B; as when resin is dissolved in spirits of wine the addition of water will throw down the resin as a precipitate, because the spirit has a stronger affinity for the water than it has for the resin. Other cases of simple and double decomposition are given in the article AFFINITY, to which we must refer, especially to the diagrams at page 22, because one of the simplest methods of dyeing depends on such a case of double decomposition as is there given. The colouring matter is produced in or upon the cloth in the form of an insoluble precipitate by mixing two solutions, in neither of which does the colour exist separately. The advantage of this method is, that the cloth can be impregnated with one solution, and then, upon immersing it in the other, the insoluble colouring matter is formed within the elongated cell or tube which forms the fibre of the cloth, so that the resulting precipitate being, as it were, imprisoned within the fibre, is rendered incapable of being removed by washing. In this way mineral colours, such as chrome-yellow, prussian-blue, iron-buff, and manganese brown, may be applied to textile fabrics. In all these cases the proper colouring matter is insoluble in water, and is precipitated whenever the two solutions proper for its formation are mixed. Thus, when an aqueous solution of bichromate of potash is mixed with an aqueous solution of acetate of lead, an insoluble precipitate of chromate of lead (chrome-yellow) is produced. In the processes for dyeing cloth with mineral colours, the fastness of the colours is supposed to be entirely a mechanical effect, in no way referable to a chemical attraction of the fibre for the colouring matter. A piece of white cotton cloth moistened with either a solution of bichromate of potash or of acetate of lead may be easily cleared of either of these salts by washing it in water; but if the cloth be first impregnated with one solution, and afterwards with the other, the precipitate of chrome-yellow produced within the fibre can never be removed by washing with water. The chrome-yellow that is afterwards washed away is merely attached loosely to the exterior of the fibre.

A second method of dyeing is with a *mordant;* this is usually a metallic salt, which has an affinity for the tissue, as well as for the colouring matter in solution; forming with the latter an insoluble compound.(1) This method of dyeing is useful for all those vegetable and animal colouring matters which are soluble in water, but have not a strong affinity for tissues. The action of the mordant is to withdraw them from solution, and to form with them, upon the cloth itself, certain compounds which are insoluble in water.

In dyeing cotton with a mordant, it is generally necessary that the mordant be produced on the cloth in a form insoluble in water; but in order that it may penetrate to the interior of the cloth about to be dyed, it must first be applied in a state of solution. The excess of mordant is then removed;(2) for, if allowed to remain, the dye would be formed chiefly on the surface, and only a small quantity would penetrate the fibre. But when the surplus mordant has been removed, and the cloth passed through the dye-beck, the resulting colour is often dull and liable to change, apparently because the quantity of mordant is too small to combine with all the colouring matter which is deposited. But on applying the same or some other mordant a second time, the colour is greatly improved in lustre, and becomes permanently attached. This second mordant is called an *alterant*. Thus, if a piece of white cotton be removed at once from a dilute solution of perchloride of tin to a weak decoction of logwood, the cloth assumes an uneven violet colour, which can be removed by washing. But if the perchloride be removed from the surface of the cloth before it is put into the decoction, the piece assumes a dull, brownish, violet tint. If a small quantity of acetate of alumina be then added to the liquor as an alterant, the cloth acquires a good permanent violet or purple colour.

When the surplus mordant has been removed, the sooner the goods are exposed to the dye-stuff, the better in general is the colour they assume.

When the dye-stuff is insoluble in water, a third method of dyeing is adopted. In such case, the mordant may be dispensed with; but it is necessary to make such a solution of the colouring substance as will allow it to be precipitated, in its insoluble state, when a cloth impregnated with the solution is exposed to some chemical agent.

The most important insoluble vegetable colours are indigo, safflower, and arnotto, and some yellow and brown dyes. To bring these into a state of solution, it is necessary to employ some other solvent than pure water. By exposing indigo to the action of some body which robs it of oxygen, it is brought to the state of *white indigo*, or *indigotin*,(3) which is soluble in water, if lime or some other alkali be present. If a piece of cloth be dipped in such a solution, it becomes impregnated with white indigo, and on exposing the cloth to the air it imbibes oxygen, by which it becomes converted into its original insoluble blue. This remains firmly attached to the fibre, and cannot be removed by washing in water. The calico to be dyed is stretched in perpendicular folds on rectangular wooden frames, as shown in Fig. 417, p. 284. The solution of indigo is contained in stone cisterns or vats, the tops of which are on a level with the ground. In preparing a new vat, fifty pounds of indigo are reduced to an impalpable powder, by grinding with water during ten or fourteen days. This powder is then mixed with hot water, and the requisite quantity of lime added, after which a solution of sulphate of iron is stirred in. Sulphate of iron consists of the protoxide of that metal dissolved in sulphuric acid: this protoxide converts the blue indigo into white indigo, which the presence of the lime enables the water to dissolve.

In the blue-dye-house at the print-works of Mr. Lees, of Manchester, visited by the writer, a man and a boy have the charge of ten vats. The calico being properly stretched, the frame is lowered into a nearly spent vat, and allowed to remain $7\frac{1}{2}$ minutes; it is then taken out, and left to drain for the same length of time, during which it becomes of a green colour; the frame is then turned over and immersed in the second vat, which contains a little more indigotin than the first; after remaining in this during $7\frac{1}{2}$ minutes, it is taken out and exposed to the air for another $7\frac{1}{2}$ minutes; it is treated in this way up to the tenth vat, which contains the largest amount of dyeing material. On being removed from this, it is of a deep blue colour.

The colouring matters of arnotto and safflower are scarcely soluble in water; but they dissolve readily in alkaline liquors, from which they may be precipitated by an acid. A piece of cloth being impregnated with an alkaline infusion of the dye stuff, is readily dyed by passing it through a weak acid. In practice, however, it is found desirable to add the acid to the alkaline infusion of the dye stuff, so as nearly to neutralize it; by this means the colouring matter is held in a state of feeble suspension, and readily attaches itself to the surface of the cloth.

The last method of dyeing which requires to be noticed in this place, is practised only on goods formed of animal tissue. By this method, which is called *mandarining*, an orange colour is given to silk and wool, not from the solution of a colouring matter, but by producing a certain change in the fibre by the action of dilute nitric acid. The orange colour is formed by the decomposition of a portion of the silk or wool by means of the acid.

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(1) Some details respecting mordants are given in the article Calico Printing, *ante*, p. 281.

(2) The superfluous mordant is removed from the surface of the cloth by passing the dried goods through a warm mixture of cow dung and water, or of dung substitute, as explained in Calico Printing, *ante*, p. 281. In a few dyeing processes, instead of dunging, the cloth is washed in a mixture of chalk and size, with hot water; the chalk serving to fix the mordant by withdrawing the small quantity of acid remaining in it. In some cases, also instead of dunging, *branning* is used; that is, washing the goods in a mixture of bran and hot water.

(3) White indigo is also called *reduced indigo* or *indigogen*. The theory of the *copperas vat*, as it is called, is complicated. It will be given under Indigo in the Appendix.

When the cloth is removed from the dye-beck, it is submitted to several finishing processes, which vary according to the method of dyeing and the nature of the stuff. It is first carefully washed in water, to separate the coloured liquid which is mechanically attached to the cloth. It is usually dried at common temperatures, but occasionally in a well ventilated apartment, heated by steam pipes. Delicate colours are always dried in the shade.

A general idea of these finishing processes may be obtained from a notice of the treatment of cotton goods, after having been dyed with a vegetable infusion, with the intervention of a mordant.

As soon as the cloth is removed from the dye-beck, it is washed in two stone cisterns of cold water, each surmounted by a reel. It is next washed at a dashwheel; or if the action of this machine be too energetic, the *rinsing* or *washing machine*, Figs. 413, 415, page 282 *ante*, is used. The cloth still retains an excess of colouring matter, which cannot be removed by cold water: it is therefore next rinsed in a mixture of bran and boiling water, or in soap and water. This *clearing*, as it is called, is also in some cases performed by putting the cloth for a few minutes into a solution of chloride of lime.

After the clearing, all the water is expelled by squeezing rollers, or by a rotatory apparatus called the *water extractor*. The wet cloth is put into a compartment between two cylinders, and the apparatus made to perform 900 or 1,000 revolutions per minute; the water is driven out by the centrifugal force through the perforations in the cylinder, whence it flows away by a gutter or drain, and in a few minutes the cloth is nearly dry.

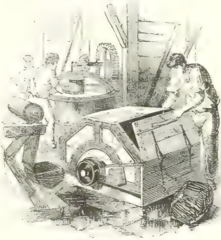


Fig. 771. WATER EXTRACTOR.

The cloth is next folded evenly, and passed, in a length of ten pieces, through the starching mangle; then through a steam drying machine, which consists of several hollow copper cylinders, each about 20 inches in diameter and 3 feet in length, filled with steam. Then comes the process of calendering, which has been already described under that head.

DYKE. Dykes or embankments form an ancient mode of defence in time of war, and examples of such earthen outworks are still to be found throughout England, either surrounding the site of old castles or fortresses, or forming a long and continuous boundary, marking the ancient division of counties. The most remarkable dykes at the present day are those of Holland, employed as a means of defence against the sea, which is ever threatening to overwhelm that extraordinary country. The greater part of Holland is below the sea-level, and consists, in fact, of land gained from the sea. Old historians speak of it as in the beginning no other than a sand-bank or more high place than ordinary, over which the tides usually flowed. This accumulation of sand checked the waters of the Rhine, and formed a bank against them, so that the mud brought down by that rapid river settled on the shores, and after long and frequent inundations produced pastures. Nature thus inviting, industrious hands were soon found, to heap up the sand seawards, and to keep as much as possible of the soil thus gained. But this soil was liable to frequent inundations, and thus a great loss of life and property occurred to those who had laboured to snatch a home from the very grasp of the waves. The history of one province in particular (Friesland) abounds with these fearful details. But the inhabitants, with wonderful tenacity, clung to their territory, and built up as fast as the sea pulled down their dykes and entrenchments. The province was inundated in the sixth and eighth centuries, and twice in the ninth century. In the twelfth century there were two inundations, and in the thirteenth there were no fewer than nine of these fearful visitations, and several of them caused important changes in the features of the country: for instance, by that of 1237 the island of Vlieland was formed; that of 1277 gave rise to the Gulf of Dollart, and swept away forty-four villages; and that of 1287 caused the Zuider Zee to assume its present extent and shape, while 80,000 persons lost their lives in the inundation. A repetition of such calamities occurred during the three succeeding centuries, until, in the sixteenth century, after a severe visitation, which swept away in different parts of Holland about a hundred thousand people, an improved method of constructing the dykes, first attempted at the beginning of that century, was more generally practised, and a law passed to enforce the keeping of them up by the owners of the land. Very strong embankments were formed, of timber filled in with large stones, and covered with earth. The dykes were raised in some places thirty feet above the ordinary level of the country, with sufficient width at the top to form a roadway. Towards the end of the sixteenth century, the practice came into use of covering the side of the dyke seawards with a layer of flags and reeds: these were twisted together in bundles, laid horizontally at the distance of three or four yards from each other, and secured to the ground by stakes. This has been found remarkably successful in retaining the earth of the dyke in its proper place, and breaking the force of the waves. These flags are continued both above and below the main action of the water, and surmounting the whole are piles driven into the dyke, and having numbers attached to them, which are referred to by the engineers charged with the maintenance of the banks. Such are the preparations seaward: towards the land, also, the dyke is well and strongly supported with piles and planking filled in with stones, and covered with earth and turf. Of course this method of forming a dyke is not the invariable one: another is thus given in Murray's Handbook:—"The first thing necessary in the construction of these bulwarks is to secure a firm solid foundation, sufficiently strong to support the immense weight to be laid upon it, by ramming down the soil, and by laying a substratum of clay, or by driving in piles, when it is incoherent. Were the foundations weak and porous, the water would dissolve and undermine it, and the dykes sink down into a hollow. The rampart is composed as far as possible of clay: whenever that material is difficult to procure, the face of the dyke is made of clay, and the interior of earth, sand, and clay; but clay alone is preferred, as being waterproof. The face of the dyke at the water-side is made very sloping; in river-dykes generally rising one foot in four or six, and in the great sea-dyke of Cappel still more gradually, as one foot in thirteen: it is protected, or in a manner thatched, by willow-twigs, interwoven so as to form a sort of wicker-work, and the interstices are filled up with clay, puddled, to render it compact. This wicker-work is renewed every three or four years, occasioning a considerable consumption of willow-boughs; and the willow-tree is cultivated to a great extent for this purpose. The dykes are frequently planted with trees, as their spreading and interlacing roots assist greatly in binding the earth together. The base is often faced with masonry, and protected by vast heaps of stones brought from a distance, and by rows of piles driven into the ground to form breakwaters to the fury of the waves. The upper part is covered with turf, and rises sometimes to the height of 40 feet. . . . The most stupendous of these embankments are the Dykes of the Helder, and of West Cappel, at the western extremity of the island of Walcheren. The annual expense of keeping in order each of them alone amounts to 75,900 guilders (about 6,400*l.*); while the sum total annually expended throughout Holland in the repair of dykes and regulation of water-levels varies from 5,000,000 to 7,000,000 guilders (nearly 600,000*l.*)."

A scientific corps of engineers is constantly and wholly employed in watching the state of the waters and guarding against accidents. In winter these officers especially watch the most dangerous spots, erecting there the necessary magazines containing stores and implements, so as to be ready at a moment's warning. Watchmen patrol the threatened line of attack day and night, and on the slightest symptom of weakness, all hands are employed to strengthen the rampart which alone stands between their country and destruction. "It may easily be imagined," says the writer already quoted, "with what intense anxiety the rising tide is at such times observed. The accumulation of waters in the ocean causes them to ascend far above the ordinary high-water mark; and if they only surmount the top of the dyke so as to flow over it, its ruin is inevitable. When such a calamity is anticipated, the alarm-bell is rung, and every man hastens to his post. With the utmost rapidity an upper rampart is constructed upon the top of the dyke to keep out the waters. It is incredible in how short a time a bulwark of this kind is elevated: it is a race between the tide and the embankment. If the strength and solidity of the dyke be doubtful, and a breach be apprehended, large sheets of sailcloth, or mats of woven straw and rushes, are laid on the outside, in the same manner as a leak is sometimes stopped in a ship. This prevents the earth's being washed away by the action of the waves. It must be remembered that the works raised on such an emergency, vast as they are, are only temporary, and are removed whenever the danger is past. Instances are not rare in which these precautions have proved quite ineffectual, and whole districts have been overwhelmed and lost for ever in the sea, or in the Rhine and its branches."

In the course of railway operations, dykes or embankments are formed on a large scale, and in many instances with great skill and caution. The details of these belong to the vast system of which they form a part, and must therefore be considered elsewhere. See RAILWAY.

DYNAMOMETER, (from *δύναμις*, strength, and *μέτρον*, a measure,) an instrument for ascertaining the relative strength of men and animals. Some valuable information might be acquired if we had the means of ascertaining easily the relative strength of an individual at different periods of life, and in different states of health. In an instrument intended to fulfil this object, invented by Mr. Grahame, and improved by Dr. Desaguliers, a steel-yard was mounted in a wooden frame, and the strength of an individual was measured by acting on the short end of the lever, so as to produce equilibrium, the position of the weight on the long arm serving as a measure. Another instrument by Leroy, consisted of a metal tube 10 or 12 inches in length, placed vertically on a foot like that of a candlestick, and containing in the inside a spiral spring, having above it a graduated shank terminating in a globe. This shank together with the spring, sank into the tube in proportion to the weight acting upon it, and thus pointed out in degrees the strength of the person who pressed on the ball with his hand"

A better instrument than either of the above, was contrived by M. Regnier, and described by him in the second volume of the Journal de l'Ecole Polytechnique. It appears that the celebrated naturalists Buffon and Guéneau desired to have an instrument for ascertaining the muscular force of a finger or of a hand, and also for estimating that of each limb separately, and of all parts of the body. Regnier's instrument does not satisfy all these conditions; the inventor admits that in the course of his experiments he had reason to be convinced that the construction of the instrument was not so easy as might have been expected. But, he says, "in addition to the use which an enlightened naturalist might make of this machine, it was possible to apply it to many other purposes. For example, it may be employed with advantage to determine the strength of draught cattle; and above all, to try that of horses, and compare it with the strength of other animals. It may serve to make known how far the assistance of well constructed wheels may favour the movement of a carriage, and what is its *vis inertiæ* in proportion to the load. We might appreciate by it what resistance the slope of a mountain opposes to a carriage, and be able to judge whether a carriage is sufficiently loaded in proportion to the number of horses that are to be yoked to it. In the arts, it may be applied to machines of which we wish to ascertain the resistance, and when we are desirous to calculate the moving force that ought to be adapted to them. It may serve also as a Roman balance to weigh burdens. In short, nothing would be more easy than to convert it into an anemometer to discover the absolute force of the wind, by fitting it to a frame of a determined size, filled up with waxed cloth; and it would not be impossible to ascertain by this machine the recoil of fire-arms, and consequently the strength of gunpowder."

This instrument is shown in Fig. 772. It consists of a steel spring s s, 12 inches long, bent into the form of an ellipsis, and covered with leather to guard the fingers when it is being strongly pressed by the hands. A semicircular plate of brass P for receiving the scales or graduated arcs is fastened to the spring by means of a piece of steel B, Fig. 773, which is attached by a claw and screws. The outer graduated arc is divided into myriogrammes, and the other into kilogrammes; each arc is still further subdivided by points which express the weight in pounds *marc;* and the various parts of the scale are determined by hanging known weights to one of the extremities of the spring. On the other branch of the spring is a small steel support D, furnished with a cleft at its upper extremity for receiving freely a small copper lever E, which is kept in its place by a steel pin *p*, Fig. 774, which shows this part of the machine on an enlarged scale. In the centre of the semicircular plate P, Fig. 772, a light steel index I is fixed upon its axis by a screw, and has a double point for indicating the divisions on both scales. A small piece of leather or cloth is glued upon the lower side of the circular part P, to render uniform and diminish the friction on the plate. The upper point of the index and the scale of myriogrammes is used in all experiments in which the spring is to be pulled in the direction of its greater axis s s, and the lower point of the index and the scale of kilogrammes is used when it is employed for experiments in which the two sides of the spring are to be compressed. This mechanism is covered with a small brass plate, Fig. 775, resting upon small cylindrical pillars *n n n*, Fig. 772, and fixed by thumb-screws. Upon this small plate is a divided arc corresponding with the first arc of the machine, and by the play of a small index *b*, Fig. 774, under the plate, the movements of the spring may be ascertained. The aperture O admits a turnscrew for the purpose of relieving or tightening the index when required. L, Fig. 773, is a brass pallet with a screw and cap, in which the lower pivot of the lever that pushes round the index plays. It acts like a spring, and yielding to any sudden concussion, prevents the mechanism from being deranged. C, Fig. 775, is a socket riveted on the small plate, in which the upper pivot of the lever turns.

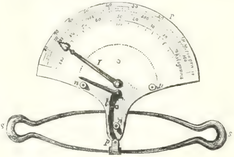


Fig. 772.

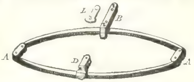


Fig. 773.

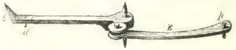


Fig. 774.

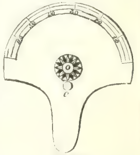


Fig. 775.

In trying the strength of the human body by means of this instrument, an iron rack is provided, on the lower part of which the feet of the person must rest, and holding in his hands a double handle of wood, as shown in Fig. 776, he exerts the strength of the reins of his body to compress or flatten the ellipse, the amount of force exerted being indicated by the index. The pin *d*, Fig. 774, pushes forward the index, which always remains at the place to which it is brought. Fig. 777, shows the method of determining the strength of the hands or the muscular force of the arms. The person lays hold of the two sides of the spring nearest to the centre, so that his arms may be a little stretched and inclined downwards at an angle of nearly 45°. Regnier considers this position to be the most natural, and that in which a man can exert his whole force.

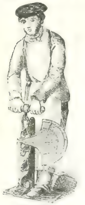


Fig. 776.

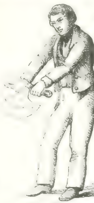


Fig. 777.

The index will then point out on the scale of kilogrammes, the force which has been exerted. If the strength of each hand be exerted separately, the sum of the two will be found equal to that of both exerted together. To ascertain the strength of animals, the dynamometer is applied as shown in Fig. 778. The animal is yoked to the chains c c, and the force which it exerts against the fixed obstacle P, is shown by the sides. The following results were obtained by M. Regnier with four good horses [the myriogramme = 22 lbs. 1 oz. 2 drs.]:—

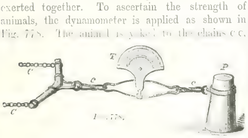


Fig. 778.

	Myriogrammes.
Force exerted by the first	36
,, ,, second	33½
,, ,, third	26½
,, ,, fourth	48
	4) 144
Mean result	36

which is equal to 736 pounds nearly.

This instrument does not weigh more than 2½ lbs.; but it is liable to a defect to which all springs are more or less subject; its elasticity diminishes in the course of time, and consequently the scale becomes deranged.

Other forms of dynamometer are shown in Figs. 779, 780, and 781. See also APPENDIX.

Fig. 779 is formed of a band of steel bent in the middle, so as to have a certain degree of flexibility. To the expanded extremity of each limb is fixed an arc of iron, which passes freely through an opening in the other limb, and terminates outside in a ring or a hook. One of these arcs is graduated, and represents in pounds the force required to bring the two limbs nearer together. Thus, if a horse were pulling a rope attached to a body which he had to move, we may imagine the rope to be severed at a certain point, and the two ends attached to the ends of the arcs, as in Fig. 779. The force of traction exerted by the animal would be seen by the greater or less bringing together of the extremities of the instrument.

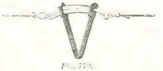


Fig. 779.

In Fig. 780, the force is measured by the collapsing of a spiral spring contained within a cylindrical case. A metal rod, occupying the axis of the cylinder, terminates at its lower extremity in a disc of metal, to which one extremity of the spring is attached. At the other end of this rod is a ring for suspending the instrument. The upper end of the spring rests against the interior of the cylinder at the top, so that when this instrument is suspended, and a weight hung on the hook at the bottom, the rod is drawn out by the collapsing of the spring; and by applying different weights the rod can in this way be graduated.

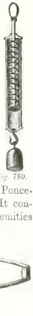


Fig. 780.

The dynamometer, Fig. 781, invented by M. Poncelet, resembles Regnier's, already described. It consists of two steel springs, connected at the extremities by a kind of hinge. The upper spring is furnished with an eye for suspending the instrument, and the lower spring with a hook for attaching a weight. The greater the weight, the greater the distance to which the two springs separate; and in this way forces are measured, by a contrivance similar to that of Regnier's instrument.

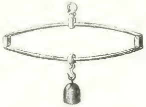


Fig. 781.

EARTHENWARE, see POTTERY.

EARTHS. This term was applied by the old chemists to certain substances which were supposed to be elementary, but are now known to be compounds of oxygen and a base; they are mostly metallic oxides, such as alumina, which is an oxide of aluminum; barytes, of barium; glucina, of glucinum; lime, of calcium; magnesia, of magnesium; silica, of silicium; strontia, of strontium; yttria, of yttrium; zirconia, of zirconium.

EAU-DE-COLOGNE is a solution of certain essential oils in alcohol. It is rendered turbid by water, which combines with the alcohol and liberates the oil. This delicious scent is manufactured at Cologne. There are 24 manufacturers in the city, several of whom bear the name of the original inventor, Jean

Marie Farina. Several millions of bottles are annually exported. The manufacture is kept secret, and a great deal of that which is sold is spurious. It is difficult to procure it genuine in England, and it is not easy by external signs to detect the spurious article: for the bottle, the seal, the description, the signature of Farina's name, the paper, and the print, are all imitated to perfection; the only failure is the *eau* itself, for we have never seen that successfully imitated. A German writer says that in order to distinguish the genuine from the spurious, rub a few drops on the hand, and the genuine eau will not smell of any spirituous liquor, or of musk, or of any foreign substance, but only of the ethereal odour proper to the water. Many recipes for its manufacture have been published, but we have no faith in any of them. The following are from Lebeaud's treatise, referred to in our article on DISTILLATION:—

Dried tops of balm mint	1 ounce.
Ditto marjoram	1 ,,
Ditto thyme	1 ,,
Ditto rosemary	1 ,,
Ditto hyssop	1 ,,
Ditto wormwood	1 ,,
Lavender flowers	2 ounces.
Angelica root	1 ounce.
Cardamom seeds	2 ounces.
Dry juniper berries	1 ounce.
Anise, cumin, fennel and caraway seeds, of each	1 ,,
Cinnamon	1 ,,
Bruised nutmegs	2 ounces.
Cloves	1 ounce.
Fresh orange peel	1 ,,
Essential oil of bergamot	1 ,,
Proof spirit of wine	1½ quarts.

Digest for some days, and then distil to dryness at a water-bath.

ANOTHER RECIPE.

Proof spirit	1½ quarts.
Tincture of balm mint	1 quart.
Ditto rosemary	1 ,,
Essential oil of cedrat	2 drams.
Ditto bergamot	,,
Ditto citron	,,
Ditto rosemary	,,
Oil of orange flowers	1 dram.

Distil at a water-bath until nothing comes over. A better eau-de-Cologne may be prepared by adding to the above:—

Essential oil of cloves	1 dram.
Essence of roses	2 ounces.
Ditto jasmin	2 ,,

These ingredients are not always distilled; but the whole are left to macerate with occasional stirring, and the clear water is then bottled.

EBULLITION. (Latin *ebullio*, to boil.) When vapour is formed from the surface only of a liquid, the process is termed EVAPORATION; but when the vapour forms and escapes from all points of the liquid mass, the process is called *boiling* or *ebullition*. The temperature at which vapour rises with sufficient force to produce ebullition is termed the *boiling point*, and the heat required to produce it varies with the nature of the fluid. Thus sulphuric ether boils at 96°, alcohol at 176°, pure water at 212°; oil of turpentine 316°, mercury 662°. The boiling point of the same liquid is constant under the same conditions, but is liable to be affected by a variety of circumstances, which will be noticed presently.

When heat is applied to the bottom of a vessel containing a liquid such as water, there is a continual displacement of the liquid particles: those near the bottom are first heated, expand, and thus becoming specifically lighter than the other particles, ascend; colder particles occupy their place, and becoming heated ascend in their turn; and thus a current is established, in which the heated particles rise up through the centre, and colder particles descend at the sides, as shown by the direction of the arrows in Fig. 782. By continuing the process the liquid particles are not only displaced, but converted into steam. If the process be carried on in a glass vessel it can be watched from the commencement, especially if the liquid contain some powder insoluble in water and of nearly the same sp. gr.: amber powder fulfils this condition; the particles of the powder follow in the course of the liquid currents. As the process continues, bubbles of vapour form on the heated sides of the vessel, rise in consequence of their levity, and burst at or near the surface. These bubbles are small in size when they first appear, but they increase in ascending; those which proceed from the hottest part of the vessel or that in immediate contact with the fire, succeed each other with the greatest rapidity. Now in order that these bubbles may form in the midst of the liquid mass which presses upon them in all directions, and ascend through it, it is evidently necessary that the steam or vapour of which they are composed should have a tension or elasticity at least equal to the surrounding pressure. It is this condition which determines the boiling points of different liquids, and also the boiling points of the same liquid under different pressures. Hence, the first condition of ebullition is, that the temperature be sufficiently high to impart to the vapour such an amount of elastic force as will enable it to overcome the pressures to which it is subject, not only from the liquid, but also from the atmosphere which presses upon the liquid. The second condition is, that such an amount of heat be present as to allow the vapour to absorb and render latent that quantity which is necessary to its existence at the temperature required. From the first condition it follows, that whatever causes the pressure on the liquid, or the elasticity of the vapour, to vary, changes also the boiling point; and from the second condition it follows, that the rapidity of ebullition, or, in other words, the conversion of the liquid into steam, depends on the quantity of heat supplied to the liquid in a given time.

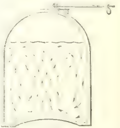


Fig. 782.

The boiling point of the same liquid is liable to change from several causes, which are themselves subject to considerable variation: viz. 1, the pressure exerted on the surface of the liquid; 2, the cohesion of the particles of the liquid; 3, the nature of the vessel containing the liquid; 4, the depth of the liquid mass; 5, the substances which the liquid may hold in solution.

1. Under ordinary circumstances, every liquid which is set to boil is under the atmospheric pressure of about 15lbs. on the square inch (see AIR), and the elasticity of the vapour must be, at least, equal to this, before it can form and escape from all parts of the liquid. As the atmospheric pressure is itself liable to variation, not only at the same place but on ascending any height, so the boiling point of a liquid is also subject to corresponding variations. At the level of the sea and under the ordinary pressure of 30 inches as indicated by the BAROMETER, water boils at 212° Fahr.; but on the summit of Mount Blanc, Saussure found that water boiled at 187°. At this temperature water, although boiling, is not sufficiently hot for the purposes of cooking food, and instances have occurred in high mountain regions, of its being impossible to boil an egg because the water was not hot enough to coagulate the albumen. Mr. Darwin relates that during an expedition to the high land in South America, the sailors were not able to cook some potatoes by boiling, a fact which they attributed to the circumstance of their having brought out a new tin pot for the purpose, which in some way or other was thought to be defective. Archdeacon Wollaston invented an apparatus, (or rather perfected an invention of Fahrenheit and Cavallo,) for measuring heights by the temperature of boiling water. It consisted of a mercurial thermometer with a very large bulb, dipping into a small portable boiler which was heated by a spirit lamp. Each degree of the scale occupied the space of about an inch, and by means of a vernier the 1,000th part of a degree could be read off. It was found that a difference of barometric pressure of 0.589 inches was equivalent to 1° in the boiling point, or 530 feet of ascent: and that the difference of the height of a common table from the ground would produce a difference in the boiling point, which was pointed out by the instrument.

As by diminishing the pressure we lower the boiling point, so, by increasing the pressure, the boiling point becomes raised. In a diving-bell, or at the bottom of a mine, water boils at a higher temperature, and is consequently hotter than at the surface, because the steam, having a greater resistance to overcome, must acquire a greater elasticity, and for this purpose it must take up a larger supply of heat. When the elasticity of the vapour of a liquid is known, its boiling point under a given pressure can easily be found, because this would be the degree of heat which imparts to the vapour sufficient elasticity to overcome the pressure. So also a liquid may be made to boil at any given temperature; all that is necessary being to make the pressure less than the tension of the vapour. And it will readily be seen that these two terms are convertible; for, as the mean pressure of the atmosphere is capable of supporting a column of mercury 30 inches high, so the vapour which rapidly escapes from water in the act of boiling, having overcome the pressure of an elastic fluid like the atmosphere, must have itself at least the same amount of elasticity. Accordingly we find that the vapour of water boiling under the ordinary atmospheric pressure, will support a column of mercury of the same height as the atmosphere; and the tension or elasticity of aqueous vapour is measured by the height of the column of mercury which it will support. Thus,

			Inches of Mercury.
At 200°	the force of vapour	of water will support	23.64
205°	,,	,,	26.13
210°	,,	,,	28.84
212°	,,	,,	30.00
213°	,,	,,	30.60
214°	,,	,,	31.21
215°	,,	,,	31.83
220°	,,	,,	34.99
225°	,,	,,	38.20
230°	,,	,,	41.75

and so on, until we arrive at such a temperature that the elasticity of the steam can no longer be restrained by the sides of the boiler, which bursts with enormous violence. This subject will be further considered under EVAPORATION and STEAM.

The foregoing statements are usually illustrated by very beautiful and instructive class experiments. One of these is termed the *hydrostatic paradox*. A Florence flask F, Fig. 783, filled about one-third with water, is placed over a spirit-lamp E until the water boils: the steam issuing from the neck of the flask will expel the air, and while the steam is thus issuing, an accurately-fitting cork S must be inserted, and this may be made further air-tight by tying a piece of moist bladder over it and a portion of the neck. The flask may now be set aside for a few minutes, until it has cooled considerably: it is then to be immersed into cold water W, contained in a glass vessel R, when the water in the flask will begin to boil again with a violence proportionate to the coldness of the water. This beautiful experiment admits of easy explanation. When the flask is plunged into cold water, it is two-thirds filled with steam: the cold immediately condenses this into water, leaving a vacuum, and consequently no pressure above. The heat left in the water is sufficient to make it boil, and it continues to do so until a fresh atmosphere forming above it exerts a pressure sufficient to prevent any further ebullition at the temperature of the flask. If, however, the flask be plunged into ice-cold water, the steam will be again condensed, and the boiling will go on as before.

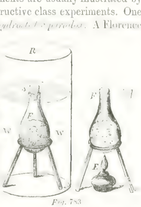


Fig. 783

Thus it will be seen that boiling may go on at almost any temperature, provided the pressure be removed. A glass of warm water under the receiver of an air-pump will boil when the air is pumped out; but the vapour that rises from it soon accumulates, and takes the place of the air in exerting a pressure, which puts an end to the boiling. To remedy this, M. Pouillet contrived an apparatus, in which the vapour is absorbed as fast as it is formed. It consists of a copper cylinder, shown in section c c, Fig. 784, closed at its upper part with a screw cap s. Before this is put in its place, a cylindrical cage of wire, full of fragments of quicklime, is placed in the copper cylinder. At the lower part is a tube *p*, which is connected with an exhausting syringe or with an air-pump, for making the vacuum. At the upper part are two bent tubes, to which are attached by screws the glass globes or other vessels containing the liquids which are to be boiled. By this arrangement cold water may be made to boil as easily as hot, and even at the freezing temperature it may be seen in violent ebullition. The difficulty of conveying a complete intelligence of experiments of this kind consists in the popular ideas connected with boiling. That a liquid should boil and not be hot seems to imply a contradiction; but we must consider that the definition of boiling is "the rapid formation of vapour at all points of a liquid," and that under ordinary circumstances this formation of vapour cannot take place, on account of the pressure of the atmosphere upon it, which is equal to about 15lbs. on every square inch. Before the liquid can boil, this pressure must be removed, and the removal is usually effected by heat. If it were not for this pressure, it would be difficult, and in many cases impossible, to procure hot water. Boiling water might be at all times procured with the greatest facility; but it would not be hot, because the water, having little or no resistance to overcome, would burst into vapour at the first application of heat, just as it does in M. Pouillet's experiment on the removal of the pressure. Indeed, if it were not for the pressure of the atmosphere, the great waters of many parts of the earth would boil from the action of the solar rays, and its existence in the liquid state would in many cases be impossible.

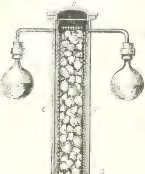
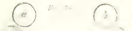


Fig. 784.

Dr. Franklin's pulse glass, Fig. 785, shows this curious property of liquids in a striking manner. A and B are two glass balls connected by a slender tube. One of them, A, is filled with water, and a small opening is left at the top of the other. On causing the water in A to boil, the vapour produced by it will expel all the air from the instrument, and when nothing but steam issues from the opening, it is closed up with a bit of wax, and the flame of a lamp being urged upon it with a blow-pipe, will close it hermetically. When the instrument is cold, grasp the ball A in the hollow of the hand; the heat of the hand will expand the bubble of vapour in it, and this vapour will drive the water into B, and blowing up through it will keep the water in B in a state of violent ebullition so long as there is any water in A. During this action B must be kept cold, in order to condense the vapour as fast as it rises up through the water. If we touch B with the warm hand or breathe upon it, the boiling ceases. When the water in A has all been driven into B, grasp B in the hand; the water will be driven into A, and the ebullition will go on in it as it did in B. While the boiling is going on in one bulb, the other will convey a sensation of cold to the hand in consequence of the rapid absorption of the heat by the particles of water converted into elastic vapour. This little toy may be suspended in the middle of the tube like a balance, and thus be placed in the inside of a window having two holes *a* and *b* cut in the pane in such a situation that when A is full of water and preponderates, B is opposite the hole *b*. When the room is sufficiently warm the vapour in A drives the water into B, which is kept cool by the air from without entering through the hole *b*. B then preponderates, and being opposite the hole *a* the process is repeated in the opposite direction. Alcohol or ether tinged with carmine are sometimes used instead of water, and act with greater facility.

Fig. 785.



The boiling of liquids at low temperatures depending on low pressures, is of great importance in the useful arts. In the refining of sugar the syrup is in this way concentrated to the granulating point without risk of decomposition, as there was before the introduction of this plan. [See SUGAR.] A similar plan has been adopted in the preparation of certain medicinal substances, the properties of which are easily impaired by heat. [See EXTRACT.] So, on the contrary, by exposing liquids to an increased pressure, we raise their boiling points in a proportionate degree. Thus in Papin's digester, [see DIGESTER,] the steam which is formed from the water having no means of escape, it exerts a pressure upon the water, and prevents the further formation of steam until the temperature of the water rises above the boiling point. This heat being conveyed to the steam, it now receives another portion of vapour without being condensed; and thus the quantity and elasticity of the steam are continually increasing with the temperature. Water has, in this way, been raised to the temperature of between 400° and 500°. Under such circumstances the solvent powers of water are greatly increased, some examples of which are given in the article BONE.

2. M. Pouillet has suggested that the cohesive attraction of the liquid may have some influence in modifying the principle, that at the boiling point the

elastic force of the vapour is equal to the superincumbent pressure. In fact, the small globules of vapour not being able to form without overcoming the cohesive attraction of the liquid particles which surround them on all sides, an additional elastic force due to a slight increase of heat is required beyond that which is necessary to overcome atmospheric pressure. When, however, the globules are once formed, the effect of cohesion is less effective, for being once overcome, the globules expand with a sort of spring, which contributes greatly to the disturbance of the liquid. If water be entirely free from air, so that the cohesion of its particles may act with the greatest effect, it can with certain precautions be heated to 275° without the cohesion of the particles giving way, or, in other words, without boiling. Some remarkable experiments on this subject are described in the article COHESION.

3. It is a remarkable fact that the boiling point of liquids is affected by the nature of the vessel containing them. Water boils a few degrees higher in a Florence flask than in an open vessel, and at a temperature 2° higher in glass than in metal, and it is only in open vessels of metal that the boiling point is regular. Liquids are converted into vapour more easily when they are placed in contact with angular and uneven surfaces than when the surfaces are smooth and polished. If a twisted piece of cold iron, metallic filings, or other finely-divided insoluble materials, be dropped into water in a glass flask which has just ceased boiling, the boiling will be resumed. Ether heated in a glass vessel had its boiling point lowered several degrees by the introduction of a few shavings of cedar; and alcohol, sp. gr. .849, had its boiling point reduced in the same way between 30° and 40°. If oil be present with water, the boiling point of the water is raised a few degrees in any kind of vessel. If a glass vessel be made perfectly clean by washing it with sulphuric acid or with potash, water may be raised in it without boiling to 220°. The adhesion between the water and the vessel is probably the cause of this irregularity; for where the vessels are thinly coated with sulphur, lac, or other material which has no adhesive attraction for water, the boiling point is sensibly lower than in clean metallic vessels. According to M. Marcet,[1] the temperature of the vapour from boiling water is the same as that of the water itself, only when the vessel, whether of glass or of metal, has a thin internal coating of some substance which has no sensible adhesion for water.

4. When the mass of liquid to be boiled has considerable depth, the inferior particles have to support, in addition to the pressure on the surface, the pressure due to the whole liquid column. If we suppose a boiler full of water to have a depth of 32 feet, the bottom layers would be under a pressure of two atmospheres, and consequently the globules of vapour could not form at a lower temperature than 250°, which is the boiling point of water at this depth and under this pressure. But the upper layers, which are under the pressure of only one atmosphere, boil at 212°; so that from the bottom upwards steam is formed at various temperatures between 250° and 212°. The bubbles of vapour formed at or near the bottom at this high temperature, ascend, and becoming suddenly condensed by the colder upper layers, produce those sudden jerks which are often inconvenient and even dangerous in boiling large masses of liquid. Where the depth of the liquid is small, a singing, simmering sound is produced, as in a kettle or a boiler of water over the fire. The bottom of the vessel in contact with the fire communicates its heat to the water in contact with it, and numerous minute bubbles of highly-elastic steam are formed; as these separate from the hot metal, they are burst in by the pressure of the fluid and the lower temperature, and the mass of water is thus thrown into a rapid and uniform vibration, producing a musical tone, which is graver or more acute according as the bubbles burst more or less rapidly in succession. The writer of the article STEAM in the Encyclopædia Britannica says — "We have observed this phenomenon in greatest perfection when we have attached a slender pipe to a close boiler producing steam, and carried its open mouth of the diameter of $\frac{1}{8}$th or $\frac{1}{10}$ths of an inch, down below the surface of cold water in a glass jar. When the mouth of the steam pipe is held just below the surface of the water, the steam issues in great rapidity in small bubbles producing an acute tone; and, on the other hand, when the pipe is held at a considerable depth, the concussions become more violent and louder, their intervals of succession greater, the tone is lowered, and finally the shocks become detached, and so violent as to shake the glass and surrounding objects with much force." Professor Robison has also remarked, that if we suddenly plunge a lump of red-hot iron into a vessel of cold water, taking care that no red part be near the surface, and apply the hand to the side of the vessel, a most violent tremor is felt, and sometimes strong thumps, arising from the collapsing of very large bubbles. If the upper part of the iron be too hot, it warms the surrounding water so much that the bubbles from below come up through it uncondensed, and produce ebullition without concussion. The great resemblance of this tremor to the sensation experienced during the shock of an earthquake, has led some to suppose that the shock is produced by the sudden contact of incandescent matter with water.

5. The boiling point of a liquid is not changed by substances mechanically suspended in it, such as sand; but it is always changed by the presence of bodies which combine chemically with it. All the soluble salts, for example, raise the boiling point of water; nevertheless the vapour from these solutions consists of water perfectly pure, without any trace of the substances dissolved.[2] The following are the

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[1] "Annales de Chimie et de Physique." 3 Série, tome v. 1842. This memoir contains much curious and important information, calculated to disturb our faith in the accuracy of the boiling point as marked upon our chemical thermometers.

[2] There appear to be some exceptions to this statement, as, for example, in the manufacture of salt from brine, as carried on in some parts of Germany. An experiment was tried at the salt works of Nauheim, in which a plate of glass was placed upon a

boiling points of a number of saturated solutions of salts:—

Name of salt	Dry salt in 100 parts of solution	Boiling point
Acetate of soda	60	256°
Nitrate of soda	60	246°
Nitrate of potash	74	238°
Sal ammoniac	50	236°
Common salt	30	224°
Sulphate of magnesia	57	222°
Alum	52	220°
Chlorate of potash	40	218°
Sulphate of copper	45	216°
Sulphate of iron	64	216°
Acetate of lead	42	215°
Sulphate of soda	31	213°

Connected with the subject of ebullition, and interesting also in an industrial point of view, are the phenomena presented by liquids on the surface of highly heated metals. The Editor, writing on this subject so far back as the year 1836,[1] has the following remarks:—"When water falls upon a red-hot iron plane surface, it suddenly divides into drops—each drop assumes a spherical form, and remains upon the plate longer than would seem natural, considering the high temperature to which it is exposed. Now, if a platinum crucible be brought near to a white heat, and water be allowed to fall into it drop by drop, the crucible may be nearly half filled with water, and be kept in this state for some minutes without any perceptible evaporation. A piece of cold glass or metal will receive no deposit of moisture, if held for a moment within the crucible, and the water suffers diminution almost imperceptibly. In this state the water will be observed to be in rapid motion, 'rotating about an axis perpendicular or nearly so to the lowest point of the dish, and at the same time its figure changes, and, from being circular in its horizontal section, becomes of an irregular oval, which contracts and dilates alternately as the mass revolves; the transverse axis contracting until its place is occupied by the conjugate, and *vice versâ*. The direction of this rotation is not at all uniform, and the mass sometimes becomes quiescent, and then assumes motion in an opposite direction. When this state of things first begins, vapour sometimes bubbles or bursts up through the liquid; but when fully established, it is most copiously given off below. In fact, the appearance is that of a stratum of vapour between the water and the bowl, which becomes at times visible when condensed at the edges.'[2] This description, which applies to water in a heated copper bowl, expresses with tolerable accuracy the phenomena presented by water in a heated platinum crucible. Much, however, depends on the quantity of water employed, and the kind of surface upon which it falls. If the platinum crucible be large, and the bottom slightly convex within, the water on reaching the bottom divides into globules, each of which is a perfect sphere, and rotates with great rapidity on its vertical axis, and at the same time it has a dancing onward sort of motion. If the bottom of the crucible be quite flat, and be kept exactly horizontal, similar effects ensue; but the experiment succeeds best when the interior of the crucible is a portion of a hollow sphere, and the inner surface perfectly clean and bright. The water must fall in slow drops, or the surface of the metal will be wetted, and steam generated; but if the drops follow each other with moderate slowness, an atmosphere of steam is immediately formed, which surrounds the globule, prevents its contact with the heated metal, and so protects it from vaporization. These facts are remarkable enough, and it is no less remarkable that if the source of heat be removed, and the crucible allowed to cool for a few minutes, a portion of the water will suddenly burst into vapour and be dissipated."

In the paper already referred to, the Editor was the first to show that other fluids behaved in the red hot crucible in a manner similar to that of water. The liquids tried were pyroligneous ether, sulphuric ether, alcohol, and mercury. Oil of turpentine, olive oil, and sulphuric acid were decomposed. In the "Student's Manual of Natural Philosophy," published in 1838, the Editor made the following observations:—"If a polished metallic vessel, such as a platinum crucible, be brought to a red or white heat, and several drops of water be allowed to fall into it, they unite into a globule, which spins rapidly round without ebullition. . . It is necessary to the success of this experiment, that the globule be not in contact with the heated metal; and accordingly we find that if the vessel be removed from the source of heat, and allowed to cool down to a certain point, a portion of the water flashes into steam by coming into contact with the heated metal. The author of this work has found that these phenomena apply also to ether, alcohol, mercury, and many saline solutions, but not to oils. He has also varied the experiment by employing a fixed oil at the temperature of 450° or 500°, instead of the heated metal. When turpentine is dropped upon it, it forms a disk with a perfectly well defined edge: the disk rotates rapidly in a horizontal plane, and soon disappears by evaporation. If several drops of sulphuric ether be placed upon the heated oil, they unite and form one large globule, which appears to be a perfect sphere: this rotates with great rapidity upon its axis, and moves rapidly over the surface of the oil. If now we place a drop of water upon the heated oil, it will form a similar figure to the ether, and behave in the same manner for an instant or two; but when the two globules come near each other, they unite and form one drop, which continues to rotate until it disappears by evaporation; or as it sometimes happens, the drop formed by the union of ether and water sinks below the surface of the oil, bursts into vapour, and scatters the oil about with considerable force. Hence much caution is required in conducting this experiment. In some cases, however, when the globule sinks below

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tall pole between two evaporating houses, distant about 1,200 paces from each other: it was found in the morning, after the drying of the dew, that the glass was covered with crystals of salt on one or the other side, according to the direction of the wind. Pallas also remarked that in the neighbourhood of the salt lakes of Asiatic Russia the dew was salt to the taste.

(1) See Mechanics' Magazine, No. 703.

(2) American Report on the Bursting of Steam Boilers.

the surface of the oil, an equable atmosphere of vapour is formed around it; so that becoming specifically lighter than the oil, it is instantly thrown up again to the surface without bursting into vapour, and it continues to rotate on the surface of the oil as before. . . Alcohol, pyroligneous ether, naphtha, and bisulphuret of carbon form globules on the surface of hot oil; which globules behave in the same manner as sulphuric ether. Ether also forms a rotating globule on the surface of hot water and hot mercury. If sulphuric acid be heated to about 400°, and a drop of ether be placed on the surface, it forms globules which dart about with astonishing rapidity: alcohol also forms globules: but naphtha and turpentine form disks which soon disappear with decomposition, and their carbon blackens the acid." In all these experiments, the drops of water were placed upon the hot surfaces by means of a pipette, which allowed them to be placed on very gently. It is curious that water, whose specific gravity is so much greater than that of hot oil, should rest upon it and move about with rapidity; but in all these cases the globules of water, ether, &c., are surrounded by steam, which serves as a sort of cushion for them to rest upon, and preserves them from contact with the heated surface whether of metal, oil, or sulphuric acid.

In the year 1845, the Editor had the pleasure of witnessing in the laboratory of King's College, London, some beautiful experiments by M. Boutigny of Evreux. This gentleman freely admitted the Editor's priority in the results above stated, and he also showed a number of beautiful experiments which tend to throw additional light on this curious condition of water, which he terms the "spheroidal state." In the first place, M. Boutigny proved that a red or white heat is not necessary in order to throw water into this globular or spheroidal form, for on dropping some water into a saucer of lead, a metal which melts long before it becomes luminous in the dark, the water rolls about like a little crystal ball for a considerable time. A spheroid of water was formed in a metallic capsule floating on oil heated to not more than 340°, which is about 600° below what is usually termed "red heat." Liquids more volatile than water become spheroidal at still lower temperatures: Alcohol at 273°; ether at 140°; and it was found in general that those liquids which require the highest temperature for boiling require also the highest to make them assume the spheroidal state.

Water and other liquids in the spheroidal state disappear by slow evaporation. A quantity of water which, under ordinary circumstances, would boil away in one minute at the temperature of 212°, will, if thrown into a vessel heated nearly to redness, require little less than an hour for its total dispersion.

The temperature of water in the spheroidal state was ascertained in the following manner. Let a large spheroid of water be formed in a tolerably thick crucible of platinum or silver, and the bulb of a small and delicate thermometer be carefully plunged into the middle of it, taking care not to allow it to come in contact with the heated metal. The temperature of the water will be found to be 205°. No variation in the temperature of the vessel containing a spheroid affects the temperature of the spheroid itself. A spheroid of water in a crucible heated considerably below redness is just as hot as one contained in a crucible heated to whiteness in a blast furnace. However high the temperature of the containing vessel may be, bodies in the spheroidal state remain constant at a temperature below that of boiling. Thus alcohol, which usually boils at 173°, never rises in the spheroidal state higher than about 170°; and ether, which boils at about 100°, when thrown into a crucible heated to whiteness does not rise above 95°. It is also remarkable that if the liquids be dropped in a boiling state into the red-hot vessels, they cool down below the boiling point in assuming the spheroidal state, and when once in this state the globules do not absorb or transmit, but reflect the rays of heat which impinge upon them.

The effect of dropping a liquid whose boiling point is very low into the red-hot crucible is truly remarkable. Sulphurous acid at the temperature of 45° cannot be kept in a liquid state, except under the pressure of two atmospheres, or about 30lbs to the square inch of surface. At a less pressure than this it bursts into vapour, and even when cooled down to 14° it boils just as water does when heated to 212°. The boiling point of sulphurous acid is therefore 14°. Now, when a few drops of this acid are allowed to fall into a red- or white-hot crucible, the temperature actually falls to 12°, in obedience to the law observed in other cases; and if water be at the same time poured into the white-hot crucible, it becomes frozen into a solid lump of ice. Dr. Faraday has even succeeded in freezing mercury in a red-hot platinum crucible: he first introduced ether into it, then solid carbonic acid, and into this mixture, in the spheroidal state, he plunged a metallic capsule containing mercury. In two or three seconds the mercury froze into a solid lump.

It has been already shown that a globule of water or other liquid is not in contact with the hot surface. This may be proved in several ways. Thus, "if a spheroid of some opaque substance be formed on a nearly flat surface, and then interposed between a lighted candle and the eye, the image of the flame is distinctly seen between the hot surface and the globule. This effect might be produced if the spheroid were in a state of rapid motion up and down, since the image of the candle, seen during the ascent, would remain visible till the next ascent; just as an ignited point in rapid revolution appears as a circle of light. That this is not the case, however, may be shown in another way. If silver be touched with nitric acid it is rapidly corroded, and in a short time dissolved. But if a quantity of nitric acid be poured into a crucible or dish of silver, sufficiently hot to induce the spheroidal state, no corrosion whatever will take place; clearly proving that the acid is at no time in absolute contact with the metal. That this is not owing to any deficiency in the strength of the acid, may be seen by placing in the spheroid a piece of cold silver, when violent action of course takes place, nitrous fumes being given off, and nitrate of silver formed." [1]

If a large spheroid of water be formed on a nearly flat surface, and a small bar of white or red hot iron be thrust into the middle of it, contact being impossible between the bar and the water, the latter forms a ring at some little distance from the heated bar, presenting very much the appearance of Saturn and his ring. So also if a lump of silver at a glowing red heat be plunged into a glass of water, as long as its bright redness is maintained, there is no ebullition, but as it slowly cools, boiling takes place. In this experiment, the glowing metal appears to form round itself an atmosphere, preventing the contact of the water, the contiguous surfaces of which appear like a silvered plate. Such phenomena as these must have some influence on the hardening and tempering of metals. If the metal to be hardened is in a highly incandescent state, the effect will not be produced on plunging it into water. A certain temperature should therefore be observed in such cases.

M. Boutigny thought that the bursting of steam boilers may be referred to the spheroidal condition of water. In illustration of this view, he exhibited the following experiment. A sphere of copper was heated, and water dropped into it: it was securely corked, and the lamp was then withdrawn. As long as the metal remained red, everything was quiet, but upon cooling, the water gradually ceased to be supported on its cushion of steam, and being brought into actual contact with the hot metal, flashed into steam, and the cork was blown out with explosive violence. We learn from Mr. Bowman's lecture that a spheroid composed of between four and five pints of water has been in this way experimented with, when the sudden formation of highly elastic steam was very striking. In this way, says M. Boutigny, is resolved the singular problem, "Required, to fill a vessel with water without wetting it, and to make the water boil by cooling the vessel."

Now, to apply a case of this kind to a steam boiler. Suppose that the engine-man neglect to supply it with water, or that the feed-pipe is out of order; the furnace all the time being in action, it is possible for all the water to be evaporated, and for the boiler to become red-hot. If, under these circumstances, water be thrown in, the first portion becomes spheroidal, and continues so until, by the addition of a larger quantity, the boiler is so far cooled that the spheroidal form can no longer be maintained: the spheroid comes in contact with the overheated boiler, bursts into steam, or, in other words, suddenly increases in bulk 1,700 times (1 cubic foot of water forming 1,700 cubic feet of steam), and the consequence is that the boiler bursts.

In Mr. Armstrong's "Treatise on Steam Boilers," published in Weale's Rudimentary Series, another very probable cause of water becoming spheroidal is mentioned. After alluding to boiler incrustations, and their action in preventing the passage of heat from the furnace to the water, owing to their non-conducting property, he says:—"It is known that an internal coating of incrustation, or boiler scale, is liable to crack, and separate into large pieces, which are thrown off from the boiler bottom at some particular degree of temperature, depending upon the thickness of the scale and the kind of substance of which it is formed. We can easily suppose that by a little hard firing, and unduly heating the boiler, a large portion of scale may be suddenly detached, uncovering a considerable area at a temperature something exceeding the maximum evaporating point, which is well known to be considerably under the lowest red-heat of iron. Now, the first effect produced will evidently be a certain amount of repulsion between the overheated iron and the water, which may continue for several seconds, and perhaps a few minutes: this may account for the sudden decrease in the supply of steam that has sometimes been observed just before the explosion of a boiler has taken place. There must also be a gradual diminution of temperature during this short space of time, in that part of the overheated iron which is exposed to the water (creating a contraction of the metal), increasing as the decreasing temperature of the iron approaches the maximum evaporating point, which is at about 350° to 400° Fahr., and causing a corresponding strain on the rivets in the boiler bottom. The direction of this strain may generally be traced on examining the bottom plates of any old boiler, and will be found to radiate in lines proceeding from the part which has been most acted on by the fire. . . . When an incrusted boiler bottom becomes highly heated, and the water at the same time too low, it very commonly happens that a large quantity of water is immediately let in, when the consequences are similar to those just described; for the internal coating of scale being suddenly contracted by the cooling effect of the water admitted, it is detached in the same manner as it would have been by the expansion of the iron, and the same effects produced, although, perhaps, more speedily, as the water admitted will reduce the temperature of the exposed part of the boiler bottom more rapidly to the maximum evaporating point.

"Whenever a boiler bottom is seen, or supposed to be, approaching to redness, (and that can only happen when the water is not boiling, or when the engine is standing,) the engine-man should be cautioned against allowing a fresh supply of water to go into the boiler, whether the boiler is short of water or not, until after the engine has been some time at work. My advice to engine-men in such cases is not to start the engine at all, but to open the fire-doors, and stand at a safe distance until all goes cool. I would not have him stop to pull the fires out, and on no account to open the safety-valve, as being little less hazardous than starting the engine. If, indeed, he knows the safety-valve to be overloaded or made fast, and the steam still continues to rise with the fire-doors open, the fire may then be quenched by a jet of water from a hose-pipe, or other safe means."

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[1] "On some remarkable properties of water," &c., a lecture read before the Royal Manchester Institution, 17th February, 1845, by J. E. Bowman, Demonstrator of Chemistry in King's College, London.

It has been found that smooth and even surfaces of metal when heated are more favourable to the spheroidal state of water or other liquids, than rough surfaces, or surfaces covered with projecting points. There is an objection to fixing projecting points in a steam-engine boiler, on account of the difficulty they would occasion in cleaning it out; but M. Boutigny suggested there should be thrown into the boiler loose pointed pieces of iron of such a shape that one of the points should always be uppermost.

The spheroidal condition of liquids helps to explain the remarkable experiment of handling molten metals, which has sometimes been mentioned in scientific books, but which no scientific man had the hardihood to repeat until M. Boutigny showed that it could be done with impunity. To mention one of numerous instances recorded of this feat, Beckmann states that in September, 1765, being at the copper-works at Awestad, one of the workmen took some of the melted copper in his hand, and after showing it to the company, threw it against a wall. He then squeezed the fingers of his horny hand close to each other, held it a few minutes under his arm-pit to make it perspire, as he said, and taking it out again, drew it over a ladle filled with melted copper, some of which he skimmed off, and moved his hand backwards and forwards very quickly by way of ostentation. M. Boutigny and M. Michel have performed similar experiments with cast-iron. The latter gentleman says:—"I divided, or cut across with my hand, a jet of cast-iron issuing from a cupola furnace, and I also plunged my other hand into a ladle of cast iron in the molten state which was fearful to look at. I trembled involuntarily in making the trial, but both hands escaped uninjured." The explanation of this experiment is that the moisture of the hand is thrown into the spheroidal state, which prevents its first contact with the molten metal, and by reflecting the radiant heat, is kept at a point below boiling. M. Boutigny's experiments were recorded in a pamphlet which is now out of print, but they are stated fully in Bouchardat's "Physique Elémentaire," Paris: 1851.

EFFERVESCENCE, a term applied to the escape of a gas from a liquid with a sort of hissing sound, resembling the simmering or boiling of water, as in soda-water powders, in which the carbonic acid of sesquicarbonate of soda is set free by the action of tartaric acid. When a liquid solvent is applied to a solid, effervescence is sometimes produced. The solution of a solid containing carbonic acid in an acid is generally conducted in a flask, and requires certain precautions. "During a cold effervescence, as of carbonate of lime in an acid, the breaking of the bubbles will throw up a shower of particles, many of which will ascend several inches perpendicularly. In these cases it will be right to incline the flask at an angle of about 45°, for then the rising drops will meet with and break against the side of the flask, and be retained. At other times, when strong currents of vapour or gas are produced at the same time with this dispersion from the breaking of bubbles, many of the particles may be carried away by the current, even when the flask or vessel may be considerably inclined. In these cases, the addition of the acid, or the application of heat, should be made cautiously, that the current may not become so rapid and attain such power as to do harm. For the same reason, operations which are liable to occasion much effervescence, should be performed in flasks of the largest size, that the current of gas within may have less velocity, and that the particles may have room and time to fall."—*Faraday*.

EFFLORESCENCE. See DELIQUESCENCE.

EIDER-DOWN. The produce of the Eider-duck, (*Somateria mollissima*,) one of the largest of the duck tribe, celebrated for the value of the down on its breast, which is extremely light and soft, and makes the warmest covering known. The native country of this bird is from about 45° north to the highest arctic latitudes yet explored. The southern European boundary of their breeding places appears to be the Faroe Islands, off the coast of Northumberland, and the rocky islands beyond Portland, in the district of Maine; but they are not very numerous in either of these localities. They always prefer to make their nests in small islands, seldom being found on the shores of a large island, or even on the mainland. On this account, the Icelanders, who are well aware of the value of this bird, take a good deal of pains to form islands by cutting off from the mainland certain of the smaller promontories, and insulating them from the coast. On these secure spots, free from the intrusion of land animals, the birds select the most proper place for the nest, which is made of tangle or sea-grass, or bundles of sea-weed, cast up by the tide, and is thickly and carefully lined with the down, which the female plucks from her breast. She is so prodigal also in this material, that she heaps it up into a thick puffed roll all round the nest, and when forced to leave her eggs in order to search for food, she prudently turns this marginal roll of down over the eggs, to keep them warm. But she cannot ensure them against the rapacity of the down-collectors. As soon as it is observed that the first eggs are laid, they are removed, and at the same time the nest is robbed of its down: the patient bird again provides a supply, but not so abundant as the first. But ere long this second supply, and the eggs embedded in it, are likewise stolen: she then makes one more attempt, sometimes, it is said, gaining a portion of down from the breast of her mate for this third nest; but when that also shares the fate of the other two, she deserts the spot in despair.

When allowed to hatch her eggs, usually four in number, she early takes the young ducks to the water, and swimming with them on her back to some distance, she makes a sudden dive, and so leaves them to swim for themselves. If the nest is disturbed, and if the first four eggs are removed, the bird goes on laying

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(1) Beckmann, "History of Inventions," vol. ii., chapter on Jugglers, &c."

for several weeks. Thus there is a double inducement to rob the nests, for the eggs furnish excellent food, and the down is greatly in request in a commercial point of view. It is sold, when cleaned, at from twelve to fourteen shillings per pound, and in one year it has produced to the Icelanders nearly 1,000*l.* sterling. The down has such extraordinary elasticity that three quarters of an ounce were sufficient to fill a large hat. It is a remarkable fact, however, that this extreme elasticity only belongs to the down plucked by the bird herself for the comfort of her young, and scarcely exists, or only in a very inferior degree, in the down taken from dead birds. No doubt the plumage is in its best condition at the time when it is wanted as a mantle for the young birds. The quantity produced is various. The contents of a first nest were once described as yielding half a pound of down; but this appears to be an extreme quantity when compared with other accounts, which make mention of less than an ounce. The latter, however, were the results obtained at the southern breeding places, and it is to be expected that the northern are more liberally supplied. The hardy inhabitants of Norway, Iceland, &c., make no use of it; but they send abundant supplies for the luxurious beds and coverlets of the wealthier classes of the south.

EIDOGRAPH, see APPENDIX.

ELAINE, see CANDLE.

ELASTICITY. The particles of solid bodies appear to be held in equilibrium by two forces, one attractive and the other repulsive, so that any mechanical force which tends to disturb them from this state is more or less resisted; and a substance is said to be more or less *elastic* according to the facility with which it regains its form, bulk, or volume when the disturbing force ceases to act.

While this property is being displayed, the change of form is evident in many bodies; as, for example, in a strip of steel fixed at one extremity: on drawing it aside by the other extremity, and leaving it to itself, it recovers its form by a series of oscillations on either side of its position of rest. It is evident that in this case the molecules have been disturbed from their position of equilibrium, and that it is the force with which they tend to return thereto that constitutes the elasticity of the body in question.

But there are many cases in which elasticity is displayed without the change of form becoming evident. For example, if we allow an ivory billiard-ball (or a ball of wood, stone, glass, or metal,) to fall upon a smooth slab of marble or of metal, it will bound up again nearly to the height from which it fell, and it would attain that height completely were it not for the resistance of the air. Now the change of form in the billiard-ball is not in this case evident, but it may be made so by covering the slab with a thin layer of oil. If we then let the ball fall upon it, and examine the spot which the ball had struck, a mark will be seen in the oil, not of a mere point, as would have been the case had the surface of the ball not yielded at the instant of impact, but a mark over a considerable surface, showing how much the ball became flattened; and this mark will be greater in proportion to the height from which the ball is allowed to fall.

The property of elasticity may be said to exist in various degrees in all substances. It is most perfect and extensive in aëriform bodies, as already explained in the article AIR, p. 27. It is perfect, but not extensive, in water and liquids generally. The means by which the elasticity of liquids was ascertained, belong to the triumphs of modern science. It was long supposed that water was incompressible, and consequently non-elastic; an assumption which derived support from an experiment made in 1661 by the Academicians of Florence. They filled a hollow ball of gold completely full of water, and submitted it to great pressure, whereby the water was made to weep through the pores of the gold, or to appear as a fine dew on the surface. The compressibility of water was proved by Œrsted, a Danish philosopher, and the apparatus used by him is shown in Fig. 786.

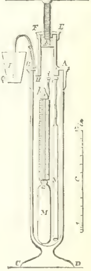

Fig. 786.

A B C D is a strong glass cylindrical vessel with a smaller metal cylinder, A E F B, fixed firmly at the top of it; this smaller cylinder contains an air-tight piston, K, movable by means of a screw. M is a glass bottle, in the neck of which is fixed by grinding, one extremity of a capillary tube, *a a*, open at both ends. The bore of this tube is very fine, and it is important to ascertain accurately the precise fraction of the contents of the whole bottle which each inch in length of its bore will hold. This is done by weighing the quantity of mercury which the bottle will hold, and the quantity which an inch of the bore of the tube will hold. In some of the tubes used by Œrsted, each inch in length was found to hold 80 millionths of the contents of the bottle. Supposing these to have been the tubes with which his experiments were made, let the bottle and tube be filled with water. Any pressure exerted upon this water which will have caused its surface in the tube to descend one inch, will have compressed it by 80 millionths of its bulk. Divisions were, however, marked upon a scale annexed to the tube, $\frac{1}{40}$th of an inch apart. A depression of the water in the tube through any one of these divisions, would thus indicate a compression of two millionths. This compression was produced in the following manner:—The bottle and its apparatus are introduced into the glass vessel A B C D, the part A E F B having been unscrewed to admit them. This vessel is then to be filled with water, and the cylinder A E F B is replaced, its piston K having been first screwed down as low as H. This piece being firmly fixed to the piston, is screwed back towards K, and in going back, water will be drawn into the vessel by the syphon B F, which communicates with a vessel of water G. When it is full, a valve closes the communication between the syphon and the vessel, and the piston K being screwed downwards, the pressure begins. This pressure is propagated from the piston and the water in the vessel through the tube *a a* to the water in the bottle; and by the law of the equal distribution of fluid pressure, the pressure thus produced within and without the bottle is precisely the same. This pressure is measured in the following manner:—N is a glass tube closed at the top and open at the bottom, and divided into equal parts by a scale marked along it. This tube being loaded by a rim of lead at the bottom, is immersed in the water of the vessel in its inverted position, and when the pressure is applied, the air contained in it is continually compressed into a less and less bulk, the diminution in bulk being precisely proportional to the pressure, according to Mariotte's law, (explained in the article AIR, q.v., pp. 27, 28.) Thus, by observing the degree to which the air is compressed in this tube, or the height to which the water is raised in it, the pressure exerted by the screw, and sustained by the water in the bottle, is always known.

In order to distinguish the descent of the surface of the water in the tube *a a*, a speck or minute bubble of air is left in the top of the tube, which is protected by a funnel-shaped cover, *p*, which is loaded at the lower edge, and inverted over it. When the instrument is sunk, this cover is nearly full of air, which by the pressure is made to occupy less and less space, and is driven into the tube; so that when the water of the vessel at length reaches the top of the tube and enters it, there is always between it and the water already within the tube a column of compressed air, forming a separation between the two, which may be easily seen through the outer glass vessel.

By means of this apparatus the compressibility of water was ascertained and its amount measured. The water sank in the tube about half-an-inch for each additional pressure of an atmosphere, or of about 15 pounds on the square inch. The compression of the water was 46.1 millionths of its bulk for each such additional pressure of one atmosphere. For each additional equal pressure, the water was compressed by the same fraction of its bulk. This law is found to govern the compression of all other bodies.[1]

The compression of other liquids was found by filling the bottle and the tube with the particular liquid to be examined. Thus the compression of mercury for every atmosphere was found to be one millionth of its bulk; of alcohol, 20 millionths; of sulphuret of carbon, 30 millionths; of water, 46.1 millionths, as already stated; of sulphuric ether, 60 millionths.[2]

When these liquids are relieved from pressure, they recover their former bulk; hence liquids may be said to be perfectly, but not extensively, elastic. It is among solids that we find the greatest diversities of this property; but it has been found by experiment that the measure of the extension or compression of uniform elastic bodies is simply proportional to the force which occasions it; at least when the forces are comparatively small. Thus, if a weight of 100 pounds lengthened a rod of steel one hundredth of an inch, a weight of 200 would lengthen it very nearly two hundredths, and a weight of 300 pounds three hundredths. The same weights acting in a contrary direction would also shorten it one, two, or three hundredths, respectively. These effects appear to be analogous to those which are more easily observable in aeriform bodies. [See AIR.]

"According to this analogy, we may express the elasticity of any substance by the weight of a certain column of the same substance, which may be denominated the *modulus* of its elasticity, and of which the weight is such, that any addition to it would increase it in the same proportion as the weight added would shorten by its pressure a portion of the substance of equal diameter. Thus, if a rod of any kind, 100 inches long, were compressed 1 inch by a weight of 1,000 lbs., the weight of the modulus of its elasticity would be 100,000 lbs., or more accurately 99,000, which is to 100,000 in the same proportion as 99 to 100. In the same manner we must suppose that the subtraction of any weight from that of the modulus will also diminish it, in the same ratio that the equivalent force would extend any portion of the substance. The height of the modulus is the same for the same substance, whatever its breadth and thickness may be; for atmospheric air it is about 5 miles, and for steel nearly 1,500. This supposition is sufficiently confirmed by experiments to be considered at least as a good approximation. It follows that the weight of the modulus must always exceed the utmost cohesive strength of the substance, and that the compression produced by such a weight must reduce its dimensions to one-half; and I have found that a force capable of compressing a piece of elastic gum [caoutchouc] to half its length, will usually extend it to many times that length, and then break or tear it; and also that a force capable of extending it to twice its length will only compress it two-thirds. In this substance, and others of a similar nature, the resistance appears to be much diminished by the facility by which a contrary change is produced in a different direction; so that the cohesion and repulsion thus estimated appear to be very weak, unless when the rigidity is increased by a great degree of cold."[3]

As the particles of solid bodies tend to return to any position out of which they have been moved, with a force proportional to their displacement, let us represent by the letter M the force required to displace the particles composing a unit of the bulk of any given solid body through a distance equal to unity: then the force requisite to produce a displacement of the same unit through a distance of D units, or parts of unity, will equal D times M, or $M\,D$. If we call this force f, then $f = M\,D$. In order to find the amount of the force M, let a rod be made of the substance whose modulus M is to be determined, having a section equal to K square units, and being L units in length. And, any given force F being applied to lengthen or compress this mass, let the corresponding alteration of length be observed, and call this l. The tension throughout the mass is the same. Every transverse section of it is, therefore, acted upon by a force equal to that force F, which is applied to its extreme section. And every unit of such a section is acted upon by a force equal to $\frac{F}{K}$. Also the extension or compression of the whole L units of length being l, each unit of length is extended or compressed through a space equal to $\frac{l}{L}$. Now, M is the force producing each unit of extension or compression in a unit of area and a unit of length. Hence, therefore, the force necessary to produce the whole of it on such a unit is $\frac{M\,l}{L}$.

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[1] Transactions of the Royal Society of Copenhagen, 1817–1822. See also Moseley's "Illustrations of Mechanics."

[2] Messrs. Colladon & Sturm have given results which differ greatly from those of Œrsted. It appears that some correction should be made for the compression of the substance of the tube and bottle, by reason of the pressure which they sustain within and without. It has been supposed that by this compression the capacity of the bottle is diminished. Œrsted has denied this, and states that the recession of water in the capillary tube was about 1½ millionths greater when bottles of lead and tin were used instead of bottles of glass.

[3] Dr. Thomas Young. Lectures on Natural Philosophy.

But the force really acting on a unit of the area of each section, and producing this extension or compression, has been shown to be $\frac{F}{K}$. Therefore, $\frac{F}{K} = \frac{M\,l}{L}$, and therefore $M = \frac{F\,L}{K\,l}$.

If E be the height in feet of a prism or bar of any substance, the weight of which prism equals the value of the force M corresponding to the elasticity of that substance, and which has a transverse section of one unit in area, then, calling w the weight of one foot of this bar, we have $w\,E = M$; $\therefore\ E = \frac{F\,L}{K\,l\,w}$. E being thus taken is the modulus of elasticity.[1]

The following are the values of the moduli of elasticity and of the force M, as determined by experiment from a variety of different substances. It is found that for compression these are generally less than for extension.

Substance.	M. The unit is here taken to be one inch.	E.	Weight which each square inch will bear without permanent alteration of structure.	Parts of its whole length that is which any portion of the mass will bear to be extended.
	lbs.	Feet	lbs	
Ash	1,640,000	4,970,000	3,540	464
Beech	1,345,000	4,600,000	2,360	570
Brass, *cast*	8,930,000	2,460,000	6,700	1,333
Cast-iron	18,400,000	5,750,000	15,300	1,204
Elm	1,340,000	5,680,000	3,240	414
Fir, *red or yellow*	2,016,000	8,330,000	4,290	470
Fir, *white*	1,830,000	8,970,000	3,630	504
Gun-metal, *cast* (8 copper, tin 1)	9,873,000	2,790,000	10,000	960
Iron, *wrought*	24,920,000	7,550,000	17,800	1,400
Larch	10,074,000	4,415,000	2,065	520
Lead, *cast*	720,000	146,000	1,500	480
Mahogany, *Honduras*	1,596,000	6,570,000	3,800	420
Marble, *white*	2,520,000	2,150,000	—	1,394
Mercury	4,417,000	750,000	—	—
Oak, *good English*	1,700,000	4,730,000	3,960	430
Pine, *American yellow*	1,600,000	8,700,000	3,900	414
Slate, *Welsh*	15,800,000	13,240,000	—	1,370
Steel	29,000,000	8,530,000	45,000	—
Stone, *Portland*	1,533,000	1,672,000	—	1,789
Tin, *cast*	4,608,000	1,453,000	2,880	1,600
Water	326,000	750,000	—	—
Whalebone	820,000	1,458,000	5,600	146
Zinc	13,680,000	4,480,000	5,700	2,400

The development of elasticity in a body depends not only on the elasticity peculiar to the substance of which it is composed, but also on its form, on the method of supporting it by fixed points, and on the point of application and direction of the force. The amount of flection which a body can be made to undergo without being permanently distorted, or broken, or, in other words, without removing the molecules beyond the limits of their elasticity, is greater in proportion as the force is applied at a greater distance from the fixed points, and as the dimensions of the body parallel to the direction of the force are small. Thus plates and discs are more flexible than masses of varying dimensions, and long laminæ, bars, and wires are more flexible still. The influence of the length of a body in the direction of the flection results from the fact that when a body is curved, the molecules are more removed from each other in proportion as they are distant from the concave surface; consequently for a given curvature there will always be a thickness in which the particles would be too much strained to maintain cohesion, and the body would break.

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[1] Moseley, Mechanics applied to the Arts.

In all those remarkable cases of elasticity developed more or less suddenly by well-known processes, as in the hardening of steel, the sudden cooling of glass, the cold hammering, rolling, and drawing of certain metals, elasticity is produced by the stable equilibrium of the molecules with respect to their relative positions. But bodies which are very ductile, and not susceptible of this kind of elasticity, may, however, under certain circumstances, acquire this property to a high degree: the elasticity is then due to the stable equilibrium of the molecules with respect to the distance of the centres of gravity. Such are the cases of iron and copper wires stretched by being fixed at their extremities and then disturbed from their position.

S. Gravesande has made numerous experiments on the elasticity of wires. The wire whose elasticity was to be determined was extended in a horizontal position between the two fixed points A and B, Fig. 787. A light scale-pan, C, suspended from a silken thread, C H, was hung upon the middle point of the wire at H, and to balance this scale-pan, a continuation of the silken thread which suspended it passed over a pulley P, and supported a counterpoise. The pulley P carried an index P G, pointing to a graduated dial-plate. Small weights were placed very gently and in succession in the scale-pan, and the deflections of the wire produced thereby were observed by the motion of the index P G. The deflection of the wire being known, and also the distance AB in a straight line, its length A′ H′ B′, corresponding to each such deflection, became known by simple geometrical rules. The difference between this length and its original length was its *elongation*. It will be seen that the weight in the scale-pan is not exerted in the direction of the length of the wire, although it does produce a certain strain or tension in that direction. The amount of this strain exerted in the direction of the length of the wire can be determined by the parallelogram of forces; [see CARPENTRY;] and it is this strain or tension which was to be compared with the elongation of the wire. It was found from these experiments that this strain was exactly proportional to the corresponding elongation; or, in other words, that the force necessary to keep the wires extended or compressed is proportional to the amount of extension or compression which they have received. For example, double the extension or compression of the same body requires double the force; triple, triple the force; and so on. So, also, one-half the compression or extension, or one-third of it, or one-fourth, requires one-half, one-third, or one-fourth the compressing or extending force. This is the law of perfect elasticity which belongs to gases and liquids, as already shown.

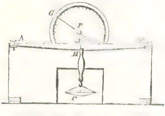

Fig. 787.

Coulomb made numerous researches on the elasticity of torsion, or the elasticity developed in wires by twisting them. His torsion balance is shown in Fig. 788, in which A B is a wire suspended by its extremity A, and stretched by a weight W. Below the weight is a needle, C D, whose extremity traverses a fixed graduated circle. Now it is evident that if the weight W be made to turn round, so that the wire may always remain in the same vertical, and the weight be then left to itself, the particles of the wire disturbed by the torsion will tend to return to their first position, and in doing so will move the weight and its attached needle; but on arriving at their first position, their acquired velocity will carry them beyond it, and they will make about this position a series of vibrations or oscillations, the amplitude of which will go on continually diminishing.

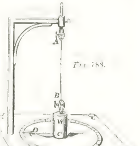

Fig. 788.

The following were the principal results obtained:—1. The force necessary to maintain the wire twisted was proportional to the angle through which the body had been twisted, and with the same wire stretched by the same weight the oscillations were ***isochronous;*** *i. e.* when the index was deflected from its position and left to itself, it returned to that position again in the same time, whether the deflection were great or small; in the one case moving faster, and in the other slower, precisely in the proportion necessary to preserve this equality of time, or isochronism.[1] 2. For the same wire stretched by a cylindrical weight the axis of which was identical with that of the needle, the duration of an oscillation is proportional to the radius of the cylinder, and to the square root of its weight. 3. The wire being loaded with different weights, the times of isochronous oscillation were as the square roots of these weights. 4. The lengths of wire being different, the times were as the square roots of these lengths. 5. The diameters of the wires being different, the times were as the square roots of these diameters.

Professor Robison instituted some experiments similar to those of Coulomb, with wires of lead and thin cylinders of pipe-clay, which show that these

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(1) Professor Moseley, in his "Illustrations of Mechanics," remarks on this point:—"It appears from the theory of Dynamics that this one observed fact is sufficient to establish the principle that 'the force with which the wire tends to return is proportional to the angle of torsion;' so that, observing the angles through which the index is twisted by the action of different forces, we can compare the forces: this is the use of the balance. The isochronism of the oscillations only obtains, however, within certain limits of torsion; thus, if an iron wire, so slender that 6 feet in length weigh but 5 grains, and 9 inches in length, be deflected, its oscillations will be isochronous so long as they do not exceed half a circumference. But if it be deflected through 3 circumferences, so as to oscillate at first through 6, then the oscillations will be slower by about $\frac{1}{3}$th than before."

apparently yielding and inelastic materials, really possess elastic properties as perfect, although not so extensive as steel. "Take a lead wire $\frac{1}{15}$th of an inch in diameter and 10 feet long; fix one end firmly to the ceiling and let the wire hang perpendicular; affix to the lower end an index like the hand of a watch; on some stand immediately below, let there be a circle divided into degrees with its centre corresponding to the lower point of the wire; now turn this index twice round and thus twist the wire. When the index is let go, it will turn backwards again, by the wire's untwisting itself, and make almost 4 revolutions before it stops; after which it twists and untwists many times, the index going backwards and forwards round the circle, diminishing, however, its arch of twist each time, till at last it settles precisely in its original position. This may be repeated for ever. Now in this motion every part of the wire partakes equally of the twist. The particles are stretched: they require force to keep them in their state of extension and recover completely their relative positions. These are all the characters of what the mechanician calls *perfect* elasticity. This is a quality quite familiar in many cases; as in glass, tempered steel, &c., but was thought incompetent to lead, which is generally considered as having little or no elasticity. But we make the assertion in the most general terms, with the limitation to moderate derangement of form. We have made the same experiment on a thread of pipe-clay, made by forcing soft clay through the small hole of a syringe, by means of a screw; and we found it more elastic than the lead-wire; for a thread of $\frac{1}{20}$th of an inch diameter and 7 feet long allowed the index to make 2 turns, and yet completely recovered its first position. But if we turn the index of the lead-wire 4 times round and let it go again, it untwists again in the same manner, but it makes little more than 4 turns back again; and after many oscillations, it finally stops in a position almost two revolutions removed from its original position. It has now acquired a new arrangement of parts, and this new arrangement is permanent like the former; and what is of particular moment, it is perfectly elastic. This change is familiarly known by the denomination of a *set*. The wire is said to have "taken a set." When we attend minutely to the procedure of nature in this phenomenon, we find that the particles have as it were slid on each other, still cohering, and have taken a new position, in which their connecting forces are in equilibrio: and in this change of relative situation, it appears that the connecting forces which maintained the particles in their first situation were not in equilibrio in some position intermediate between that of the first and that of the last form. The force required for changing this first form augmented with the change, but only to a certain degree; and during this process, the connecting forces always tended to the recovery of this first form. But after the change of mutual position has passed a certain magnitude, the union has been partly destroyed, and the particles have been brought into new situations; such that the forces which now connect each with its neighbour, tend not to the recovery of the first arrangement, but to push them further from it, into a new situation to which they now verge, and require force to prevent them from acquiring. The wire is now in fact again perfectly elastic; that is, the forces which now connect the particles with their neighbours augment to a certain degree as the derangement from this new position augments. This is not reasoning from any theory. It is narrating facts on which a theory is to be founded. What we have been just now saying, is evidently a description of that sensible form of tangible matter which we call *ductility*. It has every gradation of variety, from the softness of butter to the firmness of gold. All these bodies have some elasticity; but we say they are not perfectly elastic, because they do not completely recover their original form when it has been greatly damaged. The whole gradation may be most distinctly observed in a piece of glass or hard sealing-wax. In the ordinary form, glass is perhaps the most completely elastic body that we know, and may be bent till just ready to snap, and yet completely recovers its first form, and takes no set whatever; but when heated to such a degree as just to be visible in the dark, it loses its brittleness, and becomes so tough that it cannot be broken by any blow; but it is no longer elastic: it takes any set, and keeps it. When more heated it becomes as plastic as clay, but in this state is remarkably distinguished from clay by a quality which we call *viscidity*, which is something like elasticity, of which clay and other bodies purely plastic exhibit no appearance. This is the joint operation of strong adhesion and softness. When a rod of perfectly soft glass is suddenly stretched a little it does not at once take the shape which it acquires after some little time. It is owing to this that, in taking the impression of a seal, if we take off the seal while the wax is yet very hot, the sharpness of the impression is destroyed immediately. Each part drawing its neighbour, and each part yielding, the prominent parts are pulled down and blunted, and the sharp hollows are pulled upwards and also blunted. The seal must be kept on till all has become not only stiff but hard."[1]

The study of the laws of elasticity is most important in an industrial point of view, and will be particularly illustrated in the article, STRENGTH OF MATERIALS. This property of elasticity contributes eminently to the resources of art, and ministers largely to the uses of society. "Were it not for this property, it would be in vain that the metals should be dug out of the earth, and elaborated into various utensils. Infinitely more brittle than glass, they would immediately be dashed to pieces by the slight shocks to which everything is more or less subject; a shower of hail, or even of rain, would be sufficient to indent their surfaces, and the impact of the minute particles of dust blown against them by the wind would be sufficient permanently to destroy their polish."—*Moseley*.

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[1] Robison: System of Mechanical Philosophy vol 1

ELECTRICITY. The application of lightning-conductors to buildings and ships, in order to protect them from the destructive effects of thunder-storms, is a sufficient reason for introducing into a work on the Useful Arts such an account of the principles of this beautiful science, as will enable the reader to appreciate the advantages of these safeguards. And this is the more necessary, because there exists a great deal of misapprehension on the subject, not only in the popular, but in some cases in the professional mind; and there are still many persons to be found who would sympathise in the statement advanced by a Civil Engineer, that "science has every cause to dread the thunder-rods of Franklin: they attract destruction, and houses are safer without than with them."

The lightning of the thunder-storm is a display of electricity on a sublime scale. We are quite ignorant of the real nature of electricity, or the *electric fluid*, as it is sometimes called: and although it is everywhere present, we are not aware of its existence until it is disturbed or excited to action. This disturbance may be produced in a great variety of ways. The ancient Greeks discovered that when a piece of amber was rubbed it acquired the power of drawing light bodies towards it, or of driving them away. During many ages this was thought to be peculiar to the amber, and hence the origin of the term electricity, from the Greek word for amber, ἤλεκτρον. Many other substances answer the purpose equally well; a stick of resin rubbed with flannel, or a rod of glass rubbed with silk, exhibit this property, and become, as it is called, *electrically excited*. If one of these excited bodies be held near the cheek, a sensation will be felt similar to that produced by drawing a cob-web over the face. In the dark these excited bodies are faintly luminous, and if the finger be held near them, a small spark will dart to it, accompanied with a slight snapping noise.

The attractive and repulsive properties of electricity can be illustrated by the following simple experiment. Suspend a light downy feather in the air, by means of a thread of white silk; then take a glass tube about 3 feet long and 1 inch in diameter, perfectly dry and clean, and rub it briskly with a warm silk handkerchief; it will soon become excited, and on holding it within a few feet of the feather, the feather will fly up to it, and remain adhering to it. On withdrawing the tube, and again bringing it near to the feather, it will no longer be attracted, but repelled. The feather will escape from the action of the tube, and in this way be driven about in all directions. After some time, however, it will be again attracted, and again repelled, as before; and this attraction and repulsion may be repeated several times until the glass has lost all traces of free electricity. Figures 789, 790, show the feather in the state of attraction and repulsion.

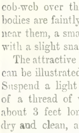
Fig. 789.
ATTRACTION.

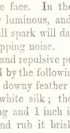
Fig 790.
REPULSION.

In this experiment, when the feather is attracted by the glass tube, it takes from it a portion of electricity, and then suffers repulsion. In a short time the feather parts with its electricity to the surrounding air, and is then in a condition to be attracted by the tube; as soon as it has obtained a fresh supply of electricity it is repelled as before. In the meantime the tube also parts with its electricity, and at length becoming neutral exerts no further action on the feather. We see, therefore, that the feather having obtained a share of electricity from the glass, is repelled by it, and as this repulsion can be proved in a variety of ways to be mutual, we may learn from this experiment the electrical law that *bodies similarly electrified repel each other.*

If this experiment be repeated with a stick of resin rubbed with dry flannel instead of glass rubbed with silk, the same result will be produced, and there will not appear to be any difference between the electricity of glass and that of resin. But on presenting to the feather first the excited glass and then the excited resin, we shall observe this remarkable fact; while the excited glass is repelling the feather, the excited resin will attract it; or, on the contrary, if we first repel the feather with the resin the glass will attract it. Or, if the excited glass be held on one side of the feather, and the resin on the other, the feather will be alternately attracted and repelled, and will swing to and fro between the two electrics.

Now, there must evidently be some difference between the electricity of glass and that of resin, since bodies which are repelled by one are attracted by the other. The electricity from glass is termed *vitreous*, and that from resin *resinous;* they are also known as *positive* and *negative*, and are represented by the symbols + *plus*, and — *minus*; a body electrified by vitreous electricity being said to be in a positive state, and that by resin in a negative.

We have seen by the last experiment, that *bodies dissimilarly electrified attract each other.* By varying the mode of performing these experiments we may learn another important truth. For example, while the feather is being repelled by the glass tube, bring near to it that part of the silk handkerchief which was used to rub the tube, and it will attract it. Or if we first present the handkerchief to the feather, it will first attract it and then repel it; and while in this state of repulsion, if the excited glass tube be held near, it will attract the feather. Hence it is obvious that the glass and the silk are in opposite states of electricity, the glass vitreous or positive, and the silk resinous or negative. A similar result will be obtained from the resin and the flannel, only it will be found that the resin is negative, and the flannel positive. Hence we arrive at the important law, that *one kind of electricity cannot be produced without the production also of the other kind;* and

Although the two kinds of electricity are distinguished by the terms positive and negative, yet there is every reason to believe that one is as much a positive force as the other; for it is impossible to produce one upon any body without the other appearing somewhere, either in near or distant bodies, just as it is impossible to pull against a fixed point without eliciting in that point an equal and opposite force.

All solid substances admit of being electrically excited by friction, but in a large number of them the electricity disappears as fast as it is formed, and hence escapes notice. If a rod of metal be held in the hand, and rubbed with silk or flannel, it would exert no action on the feather, because all the electricity, as fast as it was formed, would flow or be *conducted* through the body of the operator into the earth. But if the rod of metal be provided with a handle of glass or of resin, and then rubbed against a piece of dry warm flannel, it will attract and repel the feather. It is evident therefore that the glass or resinous handle *insulates,* or separates from surrounding objects, the metal tube, and prevents the electricity from quitting it. Other substances would do so in different degrees, and hence bodies are arranged with reference to their conducting powers. The *metals* are by far the best conductors; next to them in conducting power come well-burned *charcoal, plumbago,* concentrated and diluted *acids,* and *saline fluids, water* and *moist vegetable matter, living animal matter, flame, smoke,* and *steam.* All these substances vary greatly in conducting power. Among imperfect conductors are earth and stone, dry chalk and lime, marble and porcelain, paper and alkaline matter. Still less perfect conductors are dried vegetable and animal substances, parchment, leather, feathers, oil and fatty substances, pitch and silk. Among the worst conductors are fur and hair, dry air and gases, steam at a very high temperature, glass and all vitreous bodies, gems, talc, amber, resins, brimstone and shell-lac. By taking these substances in the reverse order, we have a list of *electrics* or *insulators;* those substances which are used for exciting electricity being the worst conductors, and consequently the best insulators; while those bodies which are the best conductors are the worst electrics and the worst insulators. It must however be borne in mind that no substance perfectly conducts or perfectly insulates. The insulating and conducting power is a difference of degree only; but the extreme differences are so great, that bodies at one end of the list may be regarded as insulators and electrics, and those at the other as conductors and non-electrics. The difference between a good conductor and a bad one may be illustrated by the fact that iron wire conducts electricity 400,000,000 times better than pure water; or in other words, the electricity meets with no more resistance in passing through an iron rod 400,000,000 of inches long, than in passing through a column of water of the same diameter only 1 inch long. The rapidity with which electricity travels is very wonderful. It has been proved by experiment that electricity moves through a copper wire $\frac{1}{13}$ inch in diameter, and about $\frac{1}{2}$ mile in length, at the rate of 576,000 miles in a second of time, a velocity greater than that of light.

It will not be necessary for our present purpose to describe the electrical machine. It consists essentially of a large plate or cylinder of glass revolving between or against fixed cushions; and as the electricity is formed, it is taken off by an insulated metal conductor, and from this it is accumulated in jars, or otherwise disposed of, in such a manner as to enable us to study its properties and exhibit its effects.

Now it is important that we should understand the method by which electricity is accumulated. This is usually done by means of the jar, which was first used by Muschenbroeck at Leyden, in 1745, and hence called the *Leyden jar.* The principle of this valuable instrument will be understood from Fig. 791, which represents a pane of glass partially coated on both sides with tin foil, leaving a margin of about an inch of the glass uncovered. This plate being supported on a stand made of some good conductor, such as metal, as in Fig. 792, we have two conducting surfaces of tin-foil, P and N, the first insulated by the pane of glass, and the other communicating freely with the earth. Let a charge of electricity be communicated to the surface P, either by means of the excited glass rod, or by a carrier-ball, *i. e.* a ball of metal hanging from a silk thread, and charged with electricity from the electrical machine. We know from a previous experiment what the effect will be: an equal charge of electricity of the opposite kind will immediately be produced on the opposite conducting surface N, just as the glass tube and the silk handkerchief produced upon each other equal charges of dissimilar electricity.

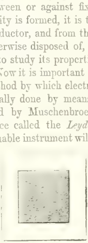

Fig. 791.

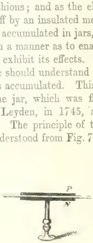

Fig. 792.

These two surfaces, thus charged with dissimilar electricities, attract each other, according to the law already stated; and this attraction, or tendency of the two equal and opposite forces to unite, so as to produce the neutral state, or state of electrical equilibrium, is so great that in many cases the glass between the two is fractured. But if a communication be made between the two surfaces by means of a good conductor, as in Fig. 793, by means of brass wires terminating in knobs, a spark passes between the knobs, the two electricities unite, and equilibrium is restored.

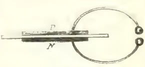

Fig. 793.

The Leyden jar, Fig. 794, is a more convenient form of apparatus than that just described. It is a glass jar, or wide-mouthed bottle, covered with tinfoil within and without, except a few inches near the top. The cover of the jar is a piece of mahogany, through the centre of which passes a brass wire with a knob at the top and a chain at the lower extremity, which extends down to the bottom of the jar, and remains in contact with the inner metallic surface. On holding the knob of the jar to the prime conductor of an electrical machine, while its plate or cylinder is being turned, sparks will fly off to the knob, and passing down the wire and chain into the jar, will communicate to the inner surface of the glass a charge of electricity, while the outside of the jar will receive an equal charge of electricity of the opposite kind. The jar is now said to be *charged;* and if, while holding the jar on the outside with one hand, the other hand be brought to the knob, a communication will thus be made by means of a conducting substance between the electricities on the inside and the outside of the jar; they will unite with a flash of light and a crackling noise, and in doing so will give a violent *shock* to the person who holds the jar.

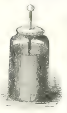
Fig. 794.

A number of these jars collected together in such a way that all the outside coatings are connected together by means of good conductors, and all the inside coatings similarly connected, forms what is called an *electrical battery*. This furnishes the means for collecting large quantities of electricity, the effects of which resemble lightning itself. By means of a large battery at Haarlem, the metallic coatings of which were equal to 225 square feet, Van Marum gave polarity to steel bars 9 inches long, nearly half an inch wide, and $\frac{1}{12}$th inch thick. A piece of boxwood, 4 inches in diameter, and 4 inches long, was rent in pieces. It melted various metals, and dispersed them in all directions. An iron wire, 25 feet long, and about $\frac{1}{140}$th inch diameter, fell under the shock into red-hot balls, dispersing in all directions. A piece of tin wire, 8 inches long, and $\frac{1}{18}$th inch diameter, disappeared in a cloud of blue smoke, throwing down red-hot globules of tin, which repeatedly rebounded from a piece of paper beneath it. During such experiments, an observer remarked that the report was so loud as to stun the ears, and the flash so bright as to dazzle the sight. When the discharge was passed through small animals it deprived them of life.

Van Marum's electrical machine consisted of two circular plates of glass, each 5 feet 5 inches in diameter, set on the same axis, and excited by revolving with friction between 8 cushions, each about 15 inches long and 2 inches wide. The power of this instrument was such that bodies at the distance of 40 feet were sensibly influenced; at the distance of 28 feet, pointed wires were tipped with a star of light; and a powerful current of brilliant light, 2 feet or more in length, crooked, and darting forth luminous brushes into the air, was obtained by presenting a metallic ball in connexion with the earth to its prime conductor. A single spark melted a considerable length of gold-leaf, and fired various kinds of combustibles.

To be able to produce and control such effects as these gives to the scientific man the power of grappling with lightning itself. If we understand the laws of the production and dispersion of this great natural force, we can take effective means for securing our buildings and our ships from its destructive attacks. Let us, therefore, endeavour, with the assistance of the principles established by the simple experiments already described, to trace the electrical conditions of a thunder-storm.

It has been shown that one kind of electricity cannot be produced without the production also of the other kind. By the friction of the glass tube with the silk the one is made + and the other —; the stick of resin is made — by the flannel, which in its turn becomes +; the square of glass, Fig. 791, being electrified positively on one surface, becomes negative on the other. In these cases, the two opposite electricities are developed very near to each other. In the glass plate they are separated only by the thickness of the glass. If we suppose this thickness to be greatly increased, and that instead of a thin pane of window-glass we have a block of glass several feet thick, partly covered, as before, with tinfoil, the metallic surface P, Fig. 795, will be insulated by the non-conducting glass, while N communicates as before with the earth. On giving a charge of positive electricity to P, there will immediately be negative electricity at N. Now suppose that, instead of this arrangement, P is a collection of clouds, as in Fig. 796, and N a portion of the earth's surface immediately below them, and that the air between them is the insulating body, instead of glass. These clouds, from some natural cause, which has not been explained, becoming electrical, will throw that part of the earth's surface immediately below them into an opposite state, and this is done through the intervention of the insulating mass of air between the two. Suppose the shaded circles in Fig. 797 to represent particles of this interposed air in a neutral state, in which the natural share of electricity belonging to each particle is equally diffused through it. If one of these particles becomes electrified, we may suppose that all the electricity of one kind is accumulated in the upper half of the particle, and all the electricity of the other kind to be in the lower half, as represented

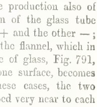

Fig. 795.

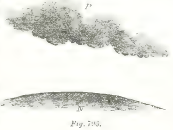

Fig. 796.

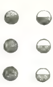
Fig. 797.

in the second group of circles. Now, something of this kind of action goes on among the innumerable particles of air between the thunder-cloud and the earth or sea beneath it. Let us trace the action of four of these particles. If the cloud P, Fig. 798, be positive, the upper half of the first particle will be thrown into a negative state, and the lower half into a positive state: this lower half of the first particle, acting on the upper half of the second particle, will render it negative. The second half of the second particle will be +: this will render the upper half of the third particle —: and the lower or + half of the third particle will render the upper half of the fourth particle —, and the lower half +, which will render the earth beneath it —. Now, as the cloud P may present to the earth a surface of several hundred square acres, and as the space between the cloud and the earth is occupied with myriads of aërial particles, all of which are being acted upon in this manner, we may gain some idea of the enormous quantity of electricity disturbed. As bodies in opposite states of electricity attract each other and tend to combine, so these particles of air, the thunder-cloud, and the earth, exert an attraction towards each other which becomes more powerful as the electrical excitement continues, until at length the whole system breaks down, the two electricities rush together with violence, producing what is called the *disruptive discharge*, or, in other words, the well-known phenomena of lightning and thunder.

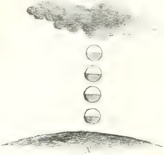

Fig. 798.

It is of no consequence in this arrangement whether the cloud be positively or negatively electrified, the effect is the same. If the cloud be negative, that portion of the earth beneath it will be electrified positively.

As the cloud and the earth are in opposite states, and are separated by the badly conducting air, it is evident that if a good metallic conductor were erected of sufficient size to reach from the earth N to the cloud P, the electricity of the cloud would be drawn quietly down into the earth without any, or at least with only a very small excitation of the intermediate air. If instead of this rod we had a system of good and bad conductors such as a church tower, the lightning would pick out, as it were, the easiest path, moving with facility along metallic bodies, and even appearing to go out of its way to pick them out. So long as the lightning moves along a good conductor it does no harm, but the moment it meets with bad conductors which delay its passage even for an instant, its destructive powers accumulate with fearful rapidity, and the most solid materials yield to it as if to some irresistible expansive force.

The electrical conditions of a thunder-storm may therefore be thus briefly summed up:—The conducting surfaces of the clouds and of the earth are the terminating planes of a highly excited mass of air which separates them: and this state of things continues until the electrical excitement of the air has attained the highest pitch, so that any tendency to further excitement renders the air incapable of resisting the combination of the two opposite electrical forces. The whole system of electrified particles of air becomes overturned, and a violent reunion of those opposite forces instantly takes place. Such a discharge is generally of a sudden and violent character, and is the cause of the damage to imperfectly conducting bodies on the earth's surface.

Among the numerous recorded cases of houses and ships being struck by lightning, it is curious in many instances to notice the devious path of the lightning, which takes advantage of all the metallic bodies in its passage as so many stepping-stones to facilitate its descent to the earth or the sea. For example, in a case described by Professor Henry, the lightning struck the top of the chimney, passed down within the flue to a point opposite a mass of iron placed on the floor of the garret, where it pierced the chimney; thence it passed explosively, breaking the plaster, into a bed-room below, where it came in contact with a copper bell-wire, and passed along this horizontally and quickly for about 6 feet; thence it leaped explosively through the air a distance of about 10 feet through a dormer window, breaking the sash, and scattering the fragments across the street. It was evidently led to this point by the upper end of a perpendicular gutter, which was near the window. It passed silently down the gutter, exhibiting scarcely any mark of its passage until it arrived at the termination, about a foot from the ground. Here again an explosion appears to have taken place, since the windows of the cellar were broken. A bed in which a man was sleeping at the time was situated against the wall, immediately under the bell-wire, and although his body was parallel to the wire and not distant from it more than 4 feet, he was not only uninjured, but not sensibly affected. The size of the hole in the chimney, and the fact that the lightning passed along the upper wire without melting it, show that the discharge was a small one, and yet the mechanical effects in breaking the plaster and projecting the window-frame across the street, were astonishingly great.

In tracing the course of any discharge of lightning through a building or a ship, the damage is always found to be produced where good conductors cease to be continued; the lightning follows the line of least resistance in its passage to the earth; it does not go out of its way to strike upon detached masses of metal, provided it has a metallic conductor of sufficient capacity to conduct it to the earth. This is illustrated in a capital experiment by Sir W. Snow

Harris. Let some small detached pieces of leaf gold *a b c d*, &c. Fig. 799, be laid on a piece of paper in any usual way, and let a disruptive discharge find its way over these detached conductors from their commencement at A to their termination at B. If the discharge be sufficient to burn up the gold, and blacken the paper, its course will be very completely shown, and it will be in the dotted line *a b d e*, &c. Fig. 800, as copied from the result of an actual experiment. The Editor has several of these papers in his possession, the results of experiments performed in his presence by Sir W. Snow Harris. It will be observed that the pieces *c* and *k* are untouched by the discharge, because from their relative positions they are of no use in facilitating the progress of the shock, and that portions of other pieces are left perfect from the same cause: thus the transverse piece *i* is blackened only in its central part, and portions of *a b d e f*, &c. remain perfect; so little tendency is there in the discharge to attack any substance not essential to its progress. If small particles of imperfect conducting matter, such as fragments of wafers, be placed in the intervals between the pieces of gold, Fig. 800, those in the course *a b d*, &c. will be dispersed in all directions, while those out of that line will be undisturbed; and this will be the case, whether the thickness of the gold be sufficient to transmit the discharge without dispersion of its parts or not. These separated pieces of leaf-gold may be taken to represent detached conductors placed at random in a building or in the masts and hull of a ship; and the general result in determining the course of the discharge of lightning will be found to be the same.

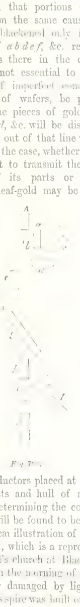

Fig. 799.

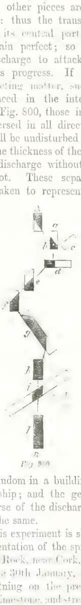

Fig. 800.

A practical illustration of this experiment is shown in Fig. 801, which is a representation of the spire of St. Michael's church at Black Rock, near Cork, as it appeared on the morning of the 30th January, 1836, after being damaged by lightning on the previous night. This spire was built of limestone, and strengthened by iron cramps and bars in the usual way within and without. An eye-witness says:—"A volume of transcendently white light burst upon us: it illuminated the whole space around, and appeared immediately over our heads; at the same instant a sharp tremulous spark ran down the steeple of the church; this was accompanied by an astounding noise, vastly greater than that of artillery. The top of the spire was swept away; the remnant twisted in various places; the square steeple was rent, and the stones scattered in all directions." The damage to the steeple was chiefly in a straight line on the windward side, which probably received the greatest quantity of rain, and so rendered it the least resisting line, but not of sufficient conductibility to carry off the discharge without damage.

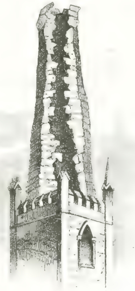

Fig. 801. AN EFFECT OF LIGHTNING.

Such of our readers as desire to study the subject of thunder-storms in full detail, are referred to the works quoted below, which are our authorities in this notice.[1] In these works will be found a multitude of cases illustrative of the various phenomena of lightning, and its effects in producing an odour of sulphur, chemical changes, the fusion of metals, and vitrifications and lightning tubes. Its astonishing mechanical effects, and its magnetic effects, are also abundantly illustrated; as also the action of lightning upon a mixed system of good and bad conductors, as shown by a detailed account of the damage done to St. Bride's Church, Fleet Street, London, in 1764; St. Martin's

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[1] "On the Nature of Thunder-storms, and on the Means of protecting Buildings and Shipping against the destructive Effects of Lightning." by Sir W. Snow Harris, F.R.S. London, 1843.

Notice *Sur le Tonnerre*, by M. Arago, published in the Annuaire of the Bureau des Longitudes, Paris, 1837.

"The Thunder-storm, or an account of the Nature, Properties, Dangers, and Uses of Lightning in various parts of the World;" by Charles Tomlinson. Published under the direction of the Committee of General Literature and Education, appointed by the Society for Promoting Christian Knowledge. 2nd Edition, 1859.

Church, London, in 1812; St. George's Church, Leicester, in 1846.

We will give a few details respecting the last named church, which was seriously damaged by lightning in 1846, selected from those which were furnished to the editor by W. Parsons, Esq., the architect of the church. The storm occurred on the 1st of August. At two in the morning of that day, it visited the Channel Islands; it then raged violently in the neighbourhood of London, and throughout the south-eastern counties; and at five in the afternoon it reached Leicester, when it continued with remarkable violence for four hours, without signs of abatement, and was not entirely over till midnight. It was at five minutes past eight o'clock, after some tremendous peals of thunder, that the church was struck. At the same instant, there was a report resembling the discharge of artillery, and a concussion of the air which shook the neighbouring houses, and extinguished a lamp burning many hundred feet distant. The fatal flash appeared like a vivid stream of light, followed by a red and globular mass of fire, and darting obliquely from the north-west, with immense velocity, against the upper part of the spire.

The results of this stroke were as follows. For the distance of 49 feet on the eastern side, and nearly 70 on the west, the massive stone-work of the spire was instantly rent asunder, and laid in ruins. Large blocks of stone were hurled in all directions, broken into small fragments, and in some cases, there is reason to believe, reduced to powder. One fragment, of considerable size, was hurled against the window of a house 300 feet distant, shattering to pieces the woodwork, as well as fourteen out of sixteen panes of glass. It is computed that on this occasion 100 tons of stone were blown to a distance of thirty feet, in three seconds. The top of the spire, when left without support beneath, fell perpendicularly inside the steeple, causing much devastation; first breaking through the upper story, and carrying away the bell and its solid supports, then entering the clock-room and breaking the works, and afterwards descending through two other strong floors, until it reached the paved vestibule, where it broke in a portion of the foundation arch.

The damage to the spire was not, however, the sole mischief done by the lightning. The pinnacles at the angles of the tower were all more or less damaged, the flying buttresses cracked through and violently shaken, many of the open battlements at the base of the spire knocked away, the roof of the church completely riddled, the roofs of the side entrances destroyed, and the stone staircase of the gallery shattered.

The course of the lightning (see Fig. 802) appears to have been as follows. The flash first struck the gilt vane, and left its marks upon the bevelled edges. Traversing the spindle and iron supports, its only path left was through a series of iron clamps separated by masses of sandstone. Here the explosion commenced, and the stone was hurled aside as the lightning descended to the lowest lead-lights of the spire. Most of these clamps were rendered powerfully magnetic, and one of them sustained a brush of steel filings at its edges after an interval of eight weeks. The lattices of the lights on three sides of the spire were little injured, but on the fourth, the lattice was singularly twisted, and partially fused.

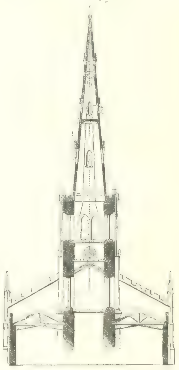


Fig. 802. SECTION OF ST. GEORGE'S CHURCH, LEICESTER.
The dotted lines show the course of the discharge.

Here the lightning diverged to the north-west pinnacle, attracted apparently by the copper bolt which held the stones together. It also traversed the large cast-iron pipe on the other side of the spire, reaching from the tower battlement to the roof, and on meeting with an inequality in the surface of the metal, it burst open and scattered to a distance portions of great solidity and weight. The lightning descended by the leaden gutters from the roof of the church to the earth. The course of the remaining current in the interior of the tower was traceable first on the lattices of the belfry, then in the clock-room, where the works were strongly magnetized, thence in three different directions to the outside of the tower. The faces of the clock were not much altered, but the hands were discoloured, and small streaks were discernible on the dial-plates, as if they had been smeared with a painter's brush. On quitting the dial-plates on the northern and southern sides of the tower, the lightning fell on the leads of the side lobbies, and was carried off by the iron pipes which descend to the earth. These pipes were chipped and injured, and one of them was perforated, as with musket-shot, a few inches from the ground. The edges of the fracture possessed magnetic power. Thus, besides the division of the current at the upper part of the spire, there was a second division in at least three directions from the clock-room and dial faces. The current had been diffused also in an extraordinary manner over the roof, and in almost every place where one piece of metal overlapped another, a powerful explosion had taken place.

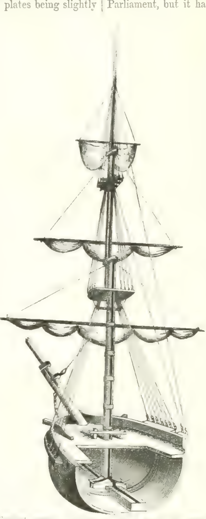
The damage to our public buildings, and even to private houses, from lightning is a matter of common notoriety, and is reported in the newspapers. It is far otherwise with ships out in the ocean: when they suffer from lightning an entry is made in the ship's log, but the public probably hears nothing on the subject. And yet the effects of lightning in the British Navy have been most disastrous. Sir W. Snow Harris has proved that since the commencement of the war in 1793, more than 250 ships suffered damage in thunder-storms. In 150 cases of damage, most of which occurred between the years 1799 and 1815, nearly 100 lower masts of line-of-battle ships and frigates, with a corresponding number of topmasts and smaller spars, together with various stores, were wholly or partially destroyed. 1 ship in 8 was set on fire in some part of the rigging or sails; upwards of 70 seamen were killed, and 133 wounded, exclusive of 19 cases in which the number of wounded is returned as "many" or "several." In one-tenth of these cases the ships were completely disabled, and they were compelled in many instances to leave their stations, and that, too, at a critical period of our history. The cost for material only in these few cases is estimated at 100,000*l.* sterling. The whole amount of loss to the public in men, money, and in services of ships, must have been very great; for in the six years between 1809 and 1815, full 30 sail-of-the-line and 15 frigates were more or less disabled. Even in time of peace, when the number of ships had been greatly reduced, many fatal accidents have occurred. On the Mediterranean station alone, between the years 1838 and 1840, 8 ships were struck by lightning, several of which were severely damaged, and 1 was set on fire. It is also highly probable that many a ship which has been reported as "missing," has been destroyed in thunder-storms, without any of the crew having been spared to record its fate. The ships of the East India Company have been especially liable to damage from lightning, from their constant traffic within the tropics, where thunder-storms are of more frequent occurrence and more violent than within the temperate zones. Our mercantile marine, engaged in active commerce in every quarter of the world, is also subject to similar attacks. Indeed, the extent of our commerce is such, that it may be said without exaggeration that the British nation is liable to damage from most of the thunder-storms that visit the earth's surface.

This liability to damage being so extensive, so sudden and unexpected in its action, and the consequences often so fatal, it is natural to suppose that attempts would be made at a very early period to obtain some means of protection against lightning. Many such attempts were made, but before and for some time after the dawn of science in modern times, the mass of superstition was so great, that the actual amount of knowledge was too small to leaven it. Nor was it until Franklin had proved the identity between common electricity and lightning by the bold experiment of bringing down "fire from heaven," that scientific men were in a condition to study the laws of thunder-storms, and devise a remedy against the attacks of lightning. Lightning conductors were invented by Franklin as a direct consequence of his beautiful electrical researches, and they were recommended by him for the protection of houses and ships from the attacks of lightning; but so little were they understood in his own day, that one of the most celebrated scientific quarrels of this country turned on the question whether the top of the conductor should be sharp or blunt. Many condemned the use of them altogether, and their value and modes of application have afforded matters for dispute up to our own day. The whole subject of lightning conductors may now, however, be said to be completely settled, in consequence of the valuable labours of Sir W. Snow Harris in the fertile field of electrical science. So long back as 1821 that gentleman submitted to the Lords of the Admiralty a plan for protecting ships from the ravages of lightning. This plan was founded upon a scientific as well as a technical knowledge of the exigencies of the case, and consisted in the application of conductors under a form so capacious and so permanently fixed, as to render them an integral part of the vessel, and independent of the crew under all circumstances. According to this plan the masts themselves are converted into lightning conductors by incorporating with them a double set of copper plates, in such a way as to produce an electric metallic line along their surface, capable of resisting any strain which the spars themselves could support: these plates are connected with bands of copper leading through the side under the deck-beams, and with the large bolts leading through the keels and keelson; and including by other connexions all the principal metallic masses employed in the construction of the hull; thus rendering the ship quite safe from any discharge of lightning which would be likely to fall upon it, by bringing the whole fabric as nearly as possible under the conditions most favourable to perfect security. Fig. 804 shows the line of conduction on the masts, from the vane-spindle to the step; and Fig. 805 represents the different connecting branches and bolts passing through the ship, in which *abcd* are connecting-bolts at the steps of the masts, and *ef* copper bands uniting these bolts. BD is the branch from the foremast, leading to the stem and the bolts *mn*. PT is the branch from the mizen-mast to the helm-port. Both these figures are copied from the engraved illustrations to the Official Instructions quoted on the next page.

The bands of copper used for these conductors are 4 feet in length, and vary from 1½ to 5 inches in width, and from ⅛ to $\frac{1}{16}$ inch in thickness. Holes are drilled in them at distances of 6 inches apart, by which they are secured to the masts by short copper

Fig. 803

nails. A shallow groove is ploughed out in the after side of each mast, and the plates being slightly curved to suit the form of the mast, are properly fixed into these grooves, so that they are closely incorporated with the round of the spar, and form, as it were, a portion of it. The plates are inserted into the grooves in a double series, placed as shown in Fig. 803, so as to allow the joints [illegible] of every two plates to fall upon the centre of another plate immediately above or below it. The method of fixing these plates is expeditious and easy, while the expense bears a very small proportion to the value of the ship, and quite vanishes when we consider how important is the protection afforded. The cost of a first-rate ship with all her stores is not less than 170,000*l.*; she carries at least 900 men, and is intended for the defence of one of the greatest maritime nations that ever existed. The cost of protecting this splendid machine from one of the most fearful calamities to which she is exposed is about 100*l.* for the expense of fixing the conductors, and the loss upon the wear of the copper, which is always reconvertible, and of constant value. A ship having been once fitted with such conductors as an integral part thereof, little or no further expense is required, and when the ship is worn out, the conductors [illegible] and fitted to a new ship at very small cost.[1]



F[illegible]. THE LINE OF [illegible] ON THE MAST [illegible]

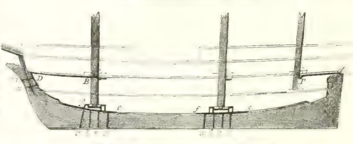


Fig. 805. CONNECTING BRANCHES AND BOLTS.

This system of conductors has not only been approved by a committee of scientific men (including the names of Wollaston and Faraday) appointed by Parliament, but it has borne the test of experience during more than 20 years, in ships which have navigated every sea, and have encountered thunder-storms of various degrees of severity. Ships thus protected have been repeatedly struck by lightning, and have escaped without injury; for by means of these conductors, the lightning has been in most cases reduced to a harmless current, of momentary duration, running down the conductor into the sea, as water flows down a pipe; and in a case where the ship was struck so violently, that, in the language of one of her officers, "she actually reeled under the force of the discharge," instead of the wreck and devastation which would certainly have followed the absence of conductors, and probably the presence of inefficient ones, no sort of damage occurred.

In the application of metallic rods to buildings or ships, it must be remembered that these structures are systems of good and bad conductors generally alternating without much method. A structure formed of good conductors, such as an iron steamboat, is perfectly safe from the attacks of lightning; so also is a man in armour safe during a thunder-storm, from the great conducting power of his covering. Lightning conductors should therefore be applied in such a way as to secure a tolerably [illegible] conducting power throughout their mass. The material of course should be metal, but metals vary in conducting power. If the conducting power of lead be taken as unity, that of tin will be 2; *i.e.* tin conducts electricity twice as well as lead; iron nearly 2½ times as well; zinc 4 times, and copper 12 times. Copper is therefore the best metal for lightning-conductors. It is certainly more costly than iron: but iron is liable to rust, and, on account of its low conducting power, is more easily melted by a discharge of lightning than copper. An electrical explosion which melts a copper wire of a given diameter, would entirely destroy an iron wire of twice that diameter. A *second* condition is, that the conductor must form one unbroken line throughout its whole extent. *Thirdly*, the metal must expose as large an extent of surface as possible, consistently with strength and durability. This is necessary on account of the great heating power of the electrical discharge; for the heat developed by a passing shock is 4 times as great when the quantity of electricity is doubled, and only ¼th as great when the diameter of the wire is doubled. Harris's conductors for buildings consist either of wide bands of copper, or of copper pipes from 1 to 2 inches in diameter, the metal of which they are formed being about ⅛ inch thick. This metal is prepared in lengths of about 10 feet, and these lengths are united by means of short intermediate pieces furnished with screws, as Fig. 806. The conductor is supported against the wall of the building by means of coupling pieces, or rings, as in Fig. 808. The upper extremity, which should project freely into the air, should be pointed somewhat like a bayonet: this pointed extremity, Fig. 807, may be about 18 inches long and ¼ inch in diameter: it is screwed into a solid plug fixed in the tubing. In cases where metallic vane-spindles, or other metallic points exist, the conductor may commence at once from them. The lower extremity of the rod has 3 divergent branches, Fig. 809, which should pass under the surface of the ground, and if circumstances permit, be connected with a spring of water, a drain, or some other conducting channel. The conductor must be applied immediately to the part to be defended, and not at a short distance from it. It must be attached to the most prominent points of the building, and if the length be very considerable, the diameter of the rod should be increased. In extensive ranges of buildings, all the most prominent parts should be furnished with conductors, as at *a b c d*, &c., Fig. 810, and be so connected by horizontal lines, such as *c n*, *d t*, *e h*, running along the ridges of roofs, &c., that a discharge of lightning falling on the general mass of the building could not possibly find its way to the ground by any circuit of which the conductor did not form a part. On this account, all great masses of metal in the neighbourhood of the conductor, which offer other possible lines of discharge, should be united with it; if this be done, no more of the discharge can pass in the direction of such masses than can be transmitted without damage.

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[1] In the "Instructions" for the application of these conductors, drawn up for the use of the Royal Dock-yards, and printed by order of the Lords Commissioners of the Admiralty, the respective widths of the copper plates for the different classes of ships are as follow:—

Line-of-battle ships down to frigates of about 1,000 tons:—

Lower masts, 4 inches; top-masts, 3 inches; top-gallant masts, 2 inches; royal pole, 2 to 1½ inch.

Corvettes below frigates of about 1,[illegible] tons to brigs of [illegible] tons:—

Lower masts—fore and main—[illegible] inches; mizen, 3 inches; top-masts, 2½ inches; top-gallant masts, 2 inches; royal pole 2 to 1 inch.

Brigs of [illegible] tons down to small craft:—

Lower masts, 3 inches; top-masts, 2 inches; top-gallant masts and royal pole, 2 inches to 1 inch.

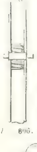


Fig. 806.

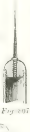
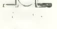


Fig. 807.



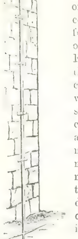


Fig. 809.

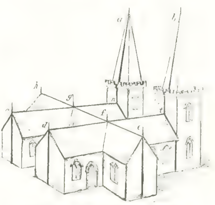


Fig. 810. SYSTEM OF LIGHTNING CONDUCTORS.

It was formerly a favourite question in electrical science as to how far the protecting power of a lightning rod extends. Leroy, in 1788, was of opinion that a conductor protected a horizontal space around it, equal to somewhat more than three times the height of the metal rod above the building to which it was attached. The physical section of the Academy of Sciences of Paris, on being consulted in 1823 by the Minister of War, expressed their opinion that a lightning conductor protects around it a circular space of which the radius is equal to the height of the rod. Other French writers state that the protecting influence of a metallic conductor extends over a space the radius of which is equal to double the height of the rod above the highest point of the building or ship to which it is attached.

Such calculations as these cannot be regarded as of any value. During a thunder-storm, the forces in operation are distributed over a great extent of surface, and the point or points upon which the lightning strikes, depend upon a peculiar electrical condition of the air between the clouds and the earth, and not upon the presence of a metallic body projecting into the air. If the air in the immediate neighbourhood of a tall building or a ship be in that state of excitement which is favourable to a disruptive discharge, such a discharge will take place upon the building or the ship; and if any damage result, its amount will depend upon the conducting power of those bodies. If the building or the ship form a line of least resistance between the cloud and the earth, the discharge will take place along that line, and it will depend upon the capacity of the lightning rods, and their good conducting power, whether the building or the ship be injured or escape without damage. If the air in the vicinity of a building or a ship be in a state of great electrical excitement, it may form a line of least resistance, and the discharge will take place along that line independently of the building or the ship. Hence it is quite impossible to say how far the influence of metallic conductors extends. All that is necessary is, to provide our structures with efficient conductors, and they will then be safe.

The prejudice once so common, that lightning conductors attract lightning, is futile. It has been proved by numerous facts, that metallic bodies exert no influence in attracting or drawing lightning aside from its path. A metallic conductor usually presents to the lightning a passive line of less resistance than that in which it is about to move; and so far the action of conductors may be to some extent beneficial in preventing a discharge from falling or continuing in an inconvenient direction, but otherwise they have really no attractive power proper to themselves, any more than a rain-pipe has an attractive power for the rain which it conducts harmlessly away.

That the French theory of the radius of protection is untrue, is proved by numerous facts. Thus, ships furnished with a lightning conductor on the mainmast only, have been struck on the foremast and severely damaged. An extensive range of buildings, furnished with a conductor proceeding from the highest point directly to the ground, may be struck at one of its lower summits, which has happened on several occasions. Hence it is of importance in ships not to trust to a conductor on one of the masts only; and in ranges of buildings it is important to distribute connected conducting lines through them, in contact with pointed conductors rising into the air from different parts.

It was formerly thought necessary to insulate the conductor, either by enclosing it within glass tubing, or by attaching it to the building with glass supports. This is not necessary, for the electrical discharge does not quit an easy line of transit, such as is furnished by a copper rod of sufficient size, to pass to other bodies out of such line. If metallic clamps be employed in the construction of a building, as in Fig. 811, the lightning in striking such building would use these clamps as stepping-stones to facilitate its descent to the earth. But if a metallic conductor be present, the lightning would disregard the clamps, and descend by this as the easiest path. There are cases, it is true, in which a division of the charge takes place, and a portion of the lightning may bound off from the conductor to other metallic bodies in connexion with the earth. Suppose the straight line, Fig. 812, to be a lightning conductor, and the bent lines portions of metallic water-pipes passing near it to the earth; then if the conductor be of small size or terminate in a very dry soil, it will offer such a resistance to the passage of the discharge that a division will probably take place. It may bifurcate or trifurcate, *i.e.* divide into 2 or 3 forks, each limb of the fork pursuing its way by a separate course to the earth, and should the metallic communication therewith be interrupted, some damage will arise. Hence it is important in arranging lightning conductors to make them of large size, and to connect them with all other masses of metal used in the structure, which lead to the ground.

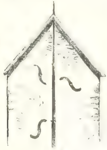


Fig. 811.

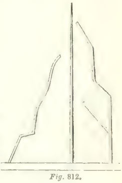


Fig. 812.

Such is a brief statement of the nature of thunder-storms, and the action of lightning conductors. It may be desirable, in conclusion, to give a few directions for the use of those persons who, being alarmed at lightning, are in houses unprotected by lightning conductors at the time of a thunder-storm. It is prudent to avoid the neighbourhood of chimneys, because lightning may enter into rooms by them, soot being a conductor of electricity. For the same reason, a person should move as far as possible from metals, and from mirrors and gilt articles. The best place seems to be in the middle of the apartment, provided there be no lamp hanging from the ceiling. A person is less exposed by avoiding contact with the walls and the floor, and hence the safest of all expedients is that recommended by Franklin, viz. to creep into a hammock suspended by silken cords in the centre of a large room. When this cannot be done, it is advisable to place between oneself and the floor some badly conducting substance. Accordingly a chair may be placed on glass, or pitch, or on mattresses. In short, the position of safety is that in which the body cannot assist as a conductor to the passage of the lightning. The position of surrounding bodies must therefore be attended to, and a person must occupy such a place, whether insulated or not, that the lightning will not make use of him as a stepping-stone in its descent to the earth. Having taken some simple precautions such as these, we may rest assured that we are secure, whatever may happen, provided we commend ourselves in sincerity to the protection of an all-wise and merciful Providence.

ELECTRIC TELEGRAPH. This instrument is the most surprising and most useful application of electrical science which has yet been made.

Among the earliest experiments in electricity were many having reference to the transmission of this force along conducting media. M. Du Fay, in 1733, appears to have observed the transmission of the electricity, from an excited glass tube, through a wet packthread 1,256 feet in length. Gordon conveyed the fluid through wires 200 ells long. Nollet, in 1746, after the invention of the Leyden phial, is said to have given a shock to 3,600 persons forming a continuous chain. Dr. Watson, in 1747, established the conducting power of the earth and of water, for the electricity of the Leyden phial. Franklin, in 1748, fired spirits by means of a charge of electricity sent through the waters of the Schuylkill river. In all these experiments, however, the transmission of the electricity seems to have been alone the object; for nothing appears to show that there was any idea in the minds of the experimenters, of using the power thus transmitted.

In 1774, Lesage at Geneva, and in 1787, Lomond in France, appear to have employed some effect of the electrical charge, (probably the divergence of pith balls,) to communicate letters and words from one room to another.

In 1794, Reusser, or Reiser, is said to have used the spark proceeding between the spaces of interrupted strips of tinfoil, to indicate letters.

Betancourt and Dr. Salva in Spain, in 1798, appear to have made experiments on the transmission of the charge through wires of great length.

In 1800, Volta invented the pile which bears his name, and shortly afterwards the decomposition of water, by the action of this pile, was discovered by Messrs. Nicholson and Carlisle.

In 1811, Soemmering at Munich, proposed to employ the current transmitted from the Voltaic pile, through any one of thirty-five insulated wires, to indicate the several letters of the alphabet and the numerals. The decomposition of water by the electricity was to be employed as the actual means of indication.

Schweigger added to this proposition of Soemmering's, a plan for calling the attention of the correspondent at the distant station, by the discharge, by the current, of a pistol charged with mixed oxygen and hydrogen gases.

In 1816, Mr. Ronalds, of Hammersmith, used the divergence and collapse of pith balls, as signals to direct the attention of an observer to the letter, which at the moment of such divergence or collapse, was in view through a small opening in a clock dial. At the two ends of the line of communication were placed clocks, going with absolute isochronism, and carrying light discs bearing letters around their circumferences. So that the clocks being started with like signals visible through an opening in a screen or dial placed before the discs, would, so long as they went perfectly together, continue to show in succession signal after signal simultaneously. The attendant at one station would therefore know, that when any letter was visible on his clock, the same letter (if the clocks went right) would be visible on the other, and he could therefore, by waiting for the appearance of the letter required on his dial, call the attention of his correspondent to this letter by suddenly charging or discharging the wire, and thus producing the divergence or collapse of the pith balls.

At this period of the history of the applications of electricity, a new and far more manageable source of electricity than the excited tube or globe was put into the hands of the philosopher. The charge produced by the excitation of glass or sulphur, had been hitherto, with one exception, used in experiments on the transmission of electricity. Now the power thus developed, called, from its source, *Frictional Electricity*, though small in quantity, is of high intensity. In fact its condition, in comparison with that developed by the Voltaic pile or battery, may be represented by very high pressure steam compared with low pressure steam. It is evidently much more easy to make joints and pipes capable of conveying the low pressure steam than that at high pressure; and just so with the two states of electricity, the degree of insulation of the conducting wire which will perfectly suffice for the low intensity, or Voltaic current, would prove no insulation at all for the high intensity or frictional charge. The invention therefore of the Voltaic pile or battery constituted a most important era in electrical applications, and its importance was still more heightened by the discovery made by Œrsted[1] in Denmark, in 1819, of the action of this current on the magnetic needle, and that of Arago and Ampère in France, and Lebeck in Berlin, of the magnetising power of the current, or of Electro-magnetism.

In 1820, Ampère suggested that the needle moved by the galvanic current might be used to give signals at a distance, and this idea was made the subject of a lecture in England, by Ritchie, in 1830. In 1832 and 1833, it appears that Baron Schilling in Russia made experiments on an instrument contrived according to Ampère's suggestion, with 36 needles and 72 wires, each needle standing for a letter or numeral. Then the movement of any needle by a current sent through its wires, indicated that the letter or numeral for which the needle stood, was to be taken as part of an intended communication.

In 1833, Gauss and Weber proposed to employ the separate movements of a single suspended bar as signals; but their arrangement must have been very delicate, and its indications very feeble and uncertain, as the signals had to be observed through a telescope placed at some distance from the oscillating bar. Mr Alexander, in 1837, exhibited a model of a proposed form of telegraph, containing 25 needles, to be acted upon in the same manner as Ampère's.

We have thus traced briefly the history of the Telegraph up to the point at which it first assumed the practical form in Cooke and Wheatstone's inventions. It must be remembered however, that the early inventors had not the full knowledge of these preliminary experiments and suggestions to guide them, as we should now have. Most of the steps just recorded, remained either entirely unknown, or were known only to a few leading men of science, until within a few years past; when the great desideratum of an electric telegraph having been suddenly and contrary to general expectation developed, each one who was in possession of any title to the merit of having believed in and experimented upon its possibility, had his title eagerly produced by his friends or fellow-countrymen.

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[1] The discovery of Œrsted consisted in this: he found that if a magnetic needle, free to turn about its centre, were placed near to and parallel with a wire, then on causing an electric current to pass through this wire, the needle would tend to be turned so as to place itself at right angles to its first position, and that the direction of this deflection followed a certain invariable law dependent on the relative positions of the wire and needle. The discovery by Ampère and Arago, which followed this after a short interval, made known the fact that if a wire were coiled about a piece of soft iron, being insulated at all points from the soft iron, then when a current was sent through the wire the iron would become suddenly magnetic, and would again as suddenly lose this power, on the cessation of the current circulating around it.

This appears to be the proper place in which to allude to the claim of Professor Morse, of America, to have been the first actual inventor of a practical electric telegraph in 1832, while on board the packet boat Sully. The Abbé Moigno states that a Mr. Jackson wrote to the Académie Française, affirming that he had, in 1832, communicated this plan to Mr. Morse while on board the Sully. Even admitting, however, all that was claimed by either party, it would only show that they did not think sufficiently well of their scheme to enter upon it, until nearly three months after the first English patent for an electric telegraph had been sealed, and the practicability of such an apparatus demonstrated in England. The first really official letter on the subject appears to be from Professor Morse, dated September 27, 1837. Cooke and Wheatstone's first patent for an electric telegraph was sealed three months before this, viz. on June 12, 1837. The difference between this telegraph and the preceding suggestions and contrivances was very great. The experiments of these gentlemen had been proceeding for a long time previously, so that when in June, 1837, their patent was obtained, it was for an arrangement in no respect of doubtful practicability, or of a form to be perfected only after trial. On the contrary, it was, within a few months after the date of the patent, put up and brought into actual and daily use, for the service of the public and of some of the railways then completed. Some of its details have since been simplified, and the modes in which the electric current is made to give the required indications to the observer, have been greatly varied, both by these gentlemen and by other persons; but the great features and principles of their first invention remain unchanged, and not only so, but they form an essential part of nearly, if not quite, all the later telegraphs of other inventors.

The various forms of apparatus used in the construction of electric telegraphs, may be resolved into a few great classes, and it is only the general features of each class that we can undertake to describe.

An electric telegraph consists of three essential parts: 1, THE BATTERY, or source of electrical power: 2, THE WIRE, or channel along which that power is conveyed to the required distant point: 3, THE INSTRUMENT, by which the electricity gives its signals, or makes evident to the observer its presence or absence, its direction or degree of intensity of action.

The *battery* in its simplest form consists of a series of zinc and copper plates connected in pairs, and placed, as shown in section, Fig. 813, in regular order in the water-tight cells of a partitioned box or *trough*, so that the copper plate of one pair and the zinc of the next are on opposite sides of the same cell. The cells are either filled with a dilute acid, or a solution of some salt, capable of acting chemically on the zinc; or the space between the plates is filled with sand moistened with such dilute acid or solution. Plates of coke, carbon, silver, or platinum, may be substituted for the copper or *negative* plate, but zinc, from its cheapness and the facility with which almost all acids dissolve it, is generally used as the *positive* plate. The screws or *terminals*, attached to the single plates at the two ends, are called the *poles* of the battery. The wires which connect the battery with the instrument, or, if more than one battery be used, which join one battery to the next, are screwed into these terminals. The screw fixed into the last single copper plate is called the *copper pole* of the battery. That fastened into the last zinc is the *zinc pole*. Any form of battery may be used in connexion with an electric telegraph, though of course some batteries, from their cheapness, constancy of action, and freedom from risk of injury, are preferable to others.

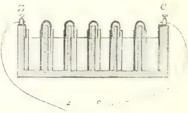

Fig. 813.

The *wire* may be called the path, along which the force from the battery is made to travel when giving a signal. Supposing a long loop of copper-wire *a g b*, Fig. 814, to be formed, and the middle of the loop to be wound in several coils or spirals, to surround at a small distance a compass needle on a stand, and if these coils be placed parallel with the needle, then the wire may represent a telegraph circuit, and the needle and its coils an instrument at a distant station. On connecting one end *a* of the wire with either of the poles of the battery, no movement will take place with the needle, for the circuit is not yet complete; but on joining the second end *b* to the other pole of the battery we complete the circuit, and the electricity can start from one pole, go all along the wire, round the needle coils and back to the second pole of the battery. Accordingly at the moment of making the connexion of the end *b*, the needle will start aside or be deflected across the coils

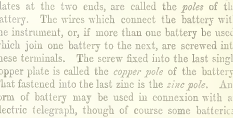

Fig. 814.

of wire. Now it will be obvious that at *c* and *e* we might have made other coils about other needles, and the same connexion would then have deflected these as well as the end needle. Those at *c* and *e* would then represent *intermediate* telegraphs or stations, between the two ends of the line, as there might be stations between London and Birmingham at Wolverton and Rugby.

In practice it has been found that if at the distant end of the line, the wire, after forming its coils *g*, is connected with the moist earth, or with the sea, or masses of water, and if at the near end we connect one pole of the battery with the moist earth, or with the sea at that place, the portion of wire *bg* becomes unnecessary, for on connecting the end *a* with the other pole of the battery, the needles will be deflected as before, the earth or sea acting as a conductor for one half the circuit, or replacing the portion *bg* of the wire. The earth is always thus employed in practice, as it saves, of course, the cost of one wire from end to end of the line.

Our piece of wire may serve for another purpose. If, while its ends are connected to the battery, and its needles consequently deflected, we lay another piece of wire across it from *c* to *d*, so as to touch both branches of the wire, we shall find that the needles will immediately fall back, or lose more or less of their deflective tendency. We have, in fact, provided another course for the electricity, which now, instead of passing all round the needle coils, proceeds from one end of the battery up one branch of the wire, across the piece from *c* to *d*, and back again to the battery. It is a principle of the electric action, that *its force in any circuit is inversely as the resistance in that circuit:* hence it is evident that nearly all the current will travel directly across by the additional wire from *c* to *d*, and scarcely any will go round by the longer course through the coils.

This explains to us the necessity of the insulation of the wire in practice, or of its being so suspended or covered, that none of the electricity can escape, till it has reached the utmost distance to which it is desired that it should travel.

We are thus led to speak of the second part of the Electric Telegraph, or of the *wires* in actual use. When passing along open parts of the lines of railway, they are suspended on posts of wood by means of rings or tubes of glass, earthenware, or porcelain. Wood is a very bad conductor of electricity, so that it would not readily allow any to escape; but glass, porcelain, and earthenware, are almost perfect insulators, and will allow no measurable quantity to escape through them. Care is taken to form the insulator so that it may be shielded from the rain, or may not easily be wetted; because water being a conductor, would, when spread over the surface of the glass or porcelain, injure its insulating power materially.

Where the wires are conducted through damp tunnels, or under streets or roads, they cannot be suspended in this manner, but are insulated by being covered completely by some material impervious to electricity, such as caoutchouc, varnished cotton, or gutta percha, the last being decidedly the best for this purpose. As the entire value of this covering depends upon its being absolutely without flaw or opening, the utmost care is taken to ensure its perfection in all parts.

It remains now to be shown how the *electric current* is made to indicate its presence or direction in the wire. In the note describing Œrsted's and Ampère's discoveries, mention was made of the action of the current on a needle and on soft iron. These actions are not simple, but present two phases, depending on the direction of the electric current through the wire. We have spoken of the force as travelling from one end or pole of the battery, through the wire to the other. It is not meant by this that any actual flow or passage of fluid does take place in the wire, but it is merely used as a convenient way of representing to our minds, that the force developed at one pole of the battery has a directive action opposite to that which it has at the other; so that when the circuit is completed, we may suppose a force to be continually coming out from the copper pole of the battery, and going in again at the zinc pole. Returning to our wire, we can then, by reversing the ends of the battery to which it is connected, make this imaginary current flow through it in one direction or the other. If when flowing in the first direction, our needle, placed in any position, were deflected to the right hand, then when made to flow in the opposite direction through the wire the same needle will be deflected to the left hand. Again, if the first direction of the current rendered one particular end of the piece of soft iron around which the wire was wound, a northern pole, then the other direction of the current would render the same end a southern pole. It will be remembered, too, that Soemmering used the decomposing or chemical power of the current in his telegraph. It is by one of these three properties of the electric force, viz. its *deflection* of a magnetic needle, its *magnetization* of soft iron, and its *decomposition* of certain chemical compounds, that the presence or absence, the direction and intensity of the current transmitted through a wire, are caused to make themselves known to the observers.

Telegraphic instruments vary greatly in their form, arrangements, and minor details of construction; but, disregarding these smaller differences, all instruments belong to one or other of the following classes:—

1. *Indicator Telegraphs* are those in which the signals are given by the movements in one or other direction, of a pointer or indicator, acted on by a coil of wire in the manner of Œrsted's magnetic needle. The telegraphs of Messrs. Cooke and Wheatstone, used generally throughout England, are of this class. Behind the dial-plate of the instrument, Fig. 815, are fixed two frames (shown from behind, and in a side view, in Fig. 816,) containing many coils of fine copper wire, covered with silk or cotton to insulate one coil from the other. Within each of these coils is suspended on a delicate axis a magnetic needle,

and on the same axes, but before the dial, hang the indicators, or *front needles*. Each of the coils has its own wire throughout the line, so that this instrument would require two distinct wires to work it. Below the dial are two handles, by means of which the clerk or attendant can connect the battery rapidly with either wire, in one or other direction, so as to deflect one or other needle to the right or to the left, or he can remove the battery connexion, and leave the wire joined up in readiness for his correspondent at any distant station to send him a signal. The needles are limited in their motions by small pins fixed in the dial, so as to be prevented from swinging too far over, and to give clearness and precision to their movements. Each station having an instrument with needles, handles, and battery complete, the clerks can see what signals they make, as well as those which are made to them by correspondents. Now, calling the left-hand needle No. 1, and the right-hand No. 2, and indicating one movement of either needle to the left by *l*, and one movement to the right by *r*, the combinations of movements which stand for the various letters of the alphabet are these:—

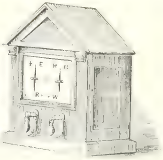

Fig. 815.

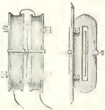
Fig. 816.

	No. 1 Needle.	No. 2 Needle.		No. 1 Needle.	No. 2 Needle.
a	*l l*		*o*		*r r*
b	*l l l*		*p*		*r r r*
c	*l*		*q*	*r*	*l*
d	*l r*		*r*	*r*	*r*
e	*r*		*s*	*r r*	*r r*
f	*r r*		*t*	*r r r*	*r r r*
g	*r r r*		*u*	*l r*	*l r*
h		*l*	*v*	*r l*	*r l*
i		*l l*	*w*	*l*	*l*
k		*l l l*	*x*	*l l*	*l l*
l		*r l*	*y*	*l l l*	*l l l*
m		*l r*	*z*	*l*	*r*
n		*r*			

It is obvious that by thus combining successive movements, the whole alphabet may be given by the use of one needle and one wire only. The communication is not so rapid as with two wires and two needles, but the construction of a line is more economical, and the system is well fitted for use between places of second-rate importance only. The needles, coils, and handles may be variously formed and arranged, according to the pleasure of different makers, but the general principles of all this class of telegraphs are the same.

The Telegraph Alarum.—For the purpose of calling the attention of an absent or inattentive clerk, an alarum is necessary. Fig. 817 shows the type of this class of instruments. A piece of soft iron of a horseshoe shape has a quantity of fine covered wire wound around it, the ends of such wire being joined to the wire on the line, so that when a current is sent through this main wire, it must pass around the coils upon the soft iron. The iron then becoming magnetic, would attract the small armature or piece of iron before it, and thus withdraw the detent from the wheel above. This releases a train of common clock-work, and the bell at the top is smartly rung by the clock-train acting on a common alarum hammer. The moment the current ceases to flow through the wire, the soft iron horseshoe loses its magnetic power, the armature is withdrawn by a small spring, and the detent once more catching the wheel, stops the clock-work. Thus at any moment the clerk at one station can sound the bell at another, so as to give notice that he wishes to make some communication. Were it not for these bells, some person would have to watch the telegraph dial incessantly, to be ready to take any signals. These alarums vary much in their construction, but the type given is one of the earliest, simplest, and most obvious forms.[1]

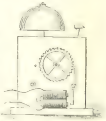
Fig 817.

The Disc Telegraph.—If we retain the electro-magnet as in the alarum, but affix to its armature, Fig. 818, instead of the detent, two light spring pieces, *b*, *c*, one carrying a hook-shaped end, and the other an obtuse wedge, or pushing piece, (termed by mechanicians a *clawker* and *driver* respectively,) and instead of the catch-wheel place a light escapement-wheel *d*, as in the figure; then each movement of the armature towards the magnet will pull the wheel round one tooth, and each recession of the armature from the magnet (by the action of a light spring) will push the wheel round another tooth. A small catch and roller may be placed above the wheel, to prevent its running forward by its own momentum more than one

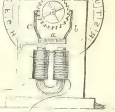

Fig. 818.

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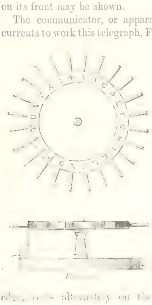
[1] In all these figures, no parts have been shown which were not absolutely connected with the action of the operating current. It is obvious that when the amount and degree of this action have been once arranged and established, many mechanical contrivances may be fitted to produce the required final result.

tooth at a time. The axis of the wheel carries a light hand or index, which points as the wheel turns round to the various letters, arranged around a disc like a clock-face. In Fig. 818, the dial seen from behind is supposed to be transparent, so that the letters painted on its front may be shown.



The communicator, or apparatus for sending the currents to work this telegraph, Fig. 819, (plan and side view,) consists of a brass disc turning freely on its centre, and bearing around its circumference the letters of the alphabet, arranged exactly as the letters on the telegraph disc. Opposite each alternate letter the brass is cut away, and a small notch of ivory inserted, so that as the disc is turned round, a spring, which bears against the edge, rests alternately on the brass and on the ivory. Ivory being a non-conductor of electricity, whenever the spring rests on an ivory notch the current is interrupted; whenever it rests on the brass, the current is transmitted. For the convenience of turning the disc to any point, it bears radiating arms, like a turnstile, one from each letter, so that by bringing each arm in succession to point to a fixed stop, the disc may be turned round step by step with ease and certainty. In the side view in the figure, all the arms but two are omitted, so as to render the sketch more distinct. Now, if the disc be standing so that its mark + (stop) is opposite to the fixed mark, its spring then resting on an ivory piece, and if at the same moment the index of the distant telegraph in connexion with it be pointing to the +, then, on moving the communicator one step forward so that letter A comes to the fixed mark, the current will be transmitted along the wire, and the magnet of the telegraph instantly draws its armature down, pulling the wheel one tooth forward, and bringing its index also to point to A. The next step of the communicator to letter B, breaks the current, the armature falls back, pushing the wheel round another tooth, and bringing its index also to B. And so to whatever letter the communicator be turned, it will in turning have made and broken the current so many times as will have brought the telegraph index step by step to the same letter; so that the clerk, by turning his communicator to one letter after the other of a word or message, can cause his correspondent's index to move to the same letters in succession, and thus spell out the same word or message. A momentary pause is made at each letter of the communication, to allow the attendant to read it off with correctness and certainty.

Many modifications of this machine have been made. In some, the armature does not actually force the wheel round, but merely controls a train of clock-work, which continually tends to turn the wheel, but can only do so, as the armature, in its to-and-fro motion, releases tooth after tooth of the escapement. In others an arrangement is made by which the armature, being itself magnetic, and therefore capable both of attraction and repulsion by the electro-magnet, draws the wheel round one way when attracted, and pushes it back the other way when repelled. By this arrangement the successive letters are more rapidly pointed out, as the index can be moved either backwards or forwards to reach the letters. Other modifications and variations also occur.

The Type-Printing Telegraph is the same as the last instrument, with the addition of a printing mechanism. Instead of the escapement axis carrying an index to point to successive letters on a fixed dial, it carries light radiating arms of steel, on the end of which are fixed common printing types *a*, Figs. 820, 821. In front of these types is placed a small roller or plate *b*, to receive the blow of a printing-hammer *c*, which stands behind the type-disc. Between this roller and the type-disc is placed the paper to receive the impression. This paper is coiled like a ribbon on a roller *d*, and is drawn off by being led between two other rollers *e*, which hold the paper tightly between them, and turn a little way round after each blow of the hammer is struck. The action, then, is this: after the type-disc has been, by the to-and-fro action of the armature, turned round so as to bring the right letter into a position to be struck, the hammer is released, and impresses by its blow this type on the ribbon of paper. At the moment that the hammer has given its blow, the drawing-rollers *e* jerk the paper forward through a space corresponding to one letter, and then the type-disc again is moved onward to the next letter required, which is struck in like manner, and so on in succession with all the letters of the communication. The hammer is usually struck by the force of a spring, released by the same train of clock-work which acts upon the drawing rollers, an arrangement being made by which the hammer cannot strike, so long as the type-disc is in motion, but falls directly the pause is made, on the right letter being brought into position. The types

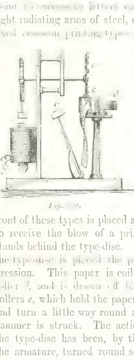


Fig. 820.

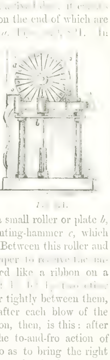


Fig. 821.

are inked by a small light roller smeared with printing-ink, which as they revolve presses lightly against their surfaces; or, in other cases, a ribbon of the carbonic ink transfer-paper is drawn round continually between the type-disc and the white paper ribbon, so that the type, on being struck by the hammer, imprints itself on the paper ribbon by means of this transfer-paper.

In this machine, also, numberless variations are made in the mode of printing the types, inking them, and drawing forward the paper.

Symbol-printing Telegraph.—In this telegraph, the electro-magnet is still employed, but not to turn a wheel. Its armature is fixed to a strong arm *a*, Fig. 822, which turns on a centre at one end and at the other carries a small steel point. The ribbon of paper is drawn slowly and steadily off from its roller *b*, by a train of common clock-work in the box *c*, driving two griping-rollers *d*. In its passage the paper goes over a brass roller *e*, which has a groove around its circumference, and the steel point on the armature arm is directly over this groove. Now, suppose that while the paper is in this way being drawn slowly and steadily over the roller *e*, the clerk at the communicating station were, by means of a common telegraph key or handle, to transmit the current for an instant: the armature would be drawn momentarily down, and the steel point, pressing upon the paper over the groove in the roller *e*, would indent it, or mark it with a depressed dot. A spring over the armature arm raises it again the moment the magnet has ceased to act. If, instead of transmitting only a momentary current, the communicating clerk were to continue the transmission during a short period, the arm would be continually pulled down, and the point, pressing on the paper as it moved onwards, would indent it with a depressed line, the length of which would depend on the duration of the current through the wire. With various combinations of these two simple marks, viz. a dot and a line, a symbolical alphabet has been constructed. The clerk can therefore, by means of a simple key for making and breaking the electric circuit, produce any one of these marks, which, after a little practice, can be read with the same facility as ordinary printing.

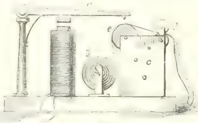
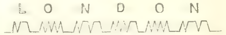


Fig. 822.

Other modifications of symbolical printing telegraphs have been contrived. In one the motion of the armature was made to raise and lower a pencil-point, which in its quiescent state continued to trace a straight line on the moving ribbon of paper, but when jerked aside by the armature, it made a _Λ__ like deviation from the line, or if the current were continued for a short time, then it traced ___/‾__ mark. In this instrument the writing appeared thus:—



The two forms of mark are, in fact, combined into a symbolic alphabet, in the same manner as the dot and line.

Chemical printing Telegraph.—In this instrument we make use of that property of the electric current, whereby certain chemical compounds are decomposed, or resolved into other compounds, on the transmission through them of this current. A common train of clock-work is employed in this, as in the last machine, to keep a ribbon of paper constantly unwinding from a drum *a*, Fig. 823, and passing over a metal roller *b*. A small steel wire *c*, connected with the wire from the line, presses lightly on the paper upon this metal roller, so that any current which may be sent through the wire shall, in its way to the earth, pass through the steel wire *c*, through the paper strip, and to the roller *b*. The paper, before being coiled on the roller *a*, is dipped in some chemical solution (of which there are many) which, though in itself nearly or quite colourless, becomes coloured when decomposed by the passage through it of an electric current. Then, by regulating the duration of this current, we can stain the paper, as it were, in dots and lines, exactly as in the last instrument we embossed it with dots and lines; the key used for this purpose being the same as in the last. In fact, the two machines resemble one another in many points, but differ in this, that in the first the current, by its mechanical action on the armature, embosses or stamps its marks on the paper; in the second, by the direct passage of the current through the prepared paper, this becomes stained or dyed in parts with symbolical markings. The same alphabet of marks will serve for both machines.

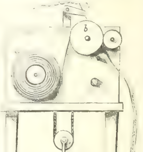


Fig. 823.

A most ingenious modification of this principle has been made in the *Writing Telegraph*. It is evident that if, instead of employing a long ribbon of paper, we took just length enough of it to pass once round the roller *b*, and if we gave this roller not only a rotation on its axis, but also, by means of a screw, a slow advance from side to side as it rotated, then the steel wire would trace on the paper a spiral line like the thread of the screw, which shifted endways the roller *b*. Now if also, instead of communicating by a key, we had at the other end another roller exactly like *b*, and which by means of clock-work we could turn at precisely the same speed as *b*, and with the same rate of shift endwise, then a tracer resting on this second roller would, if the current were kept continuously passing, trace precisely the same spiral as the wire on the first roller *b*. But supposing, further, that the current were only maintained by the pressure of this tracer against the metal of its roller; then if on the surface of this roller we placed a bit of any non-conducting material, as shell-lac or resin, when the tracer passed over this as the roller turned round, the wire at the roller *b* would cease to make its stained mark, while the tracer was passing over the non-conductor, and would begin again to mark directly the tracer had again come upon the metal. Now to use this machine, the words are written on a slip of tinfoil in a non-conducting varnish. As soon as this is dry the tinfoil is wrapped around the tracer roller, and the tracer being made to bear upon it, the two rollers, one at the communicating and the other at the receiving station, are started at the same moment. Then while the tracer rests on the tinfoil, (which is a conductor of electricity,) the wire on roller *b* will continue to make its stained spiral line on the prepared paper; but whenever in its passage the tracer rests on a piece of the varnished writing, the current will be broken, and the spirals traced by the steel wire will be interrupted. Hence we can see that the interruptions on the paper round the roller *b*, will exactly coincide with the writing which has passed under the tracer, and we shall have on unfolding this paper from the roller, a fac-simile of the original writing, which will appear in clear spaces left free from the parallel lines traced close together over every other part of the paper. This fac-simile will appear much like Fig. 824. By means of this instrument, the actual handwriting of a correspondent may be said to be transmitted.

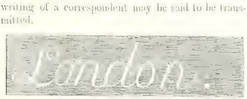


Fig. 824.

Some few forms of telegraph have been proposed which scarcely come under any of these classes, but such forms are rather curiosities of the lecture room than really practical telegraphs, and it is therefore unnecessary to occupy space in describing them. The classes above given include every form which has at present been brought into any really extensive and useful application.

At the present time, the question of the practicability of laying down the electric telegraph between places separated by seas or by wide rivers, occupies much attention among practical electricians. From what we have said of the transmission of the current, at the commencement of this article, it is obvious that the whole gist of the matter lies in the inquiry, whether a wire can be so covered and protected, as to remain permanently insulated and uninjured beneath the water. Among the various materials proposed for the covering, gutta percha seems at present the most promising of success. But this requires to be protected from abrasion by tides and currents acting on the sand and shingle of the bottom, and the wire itself must be guarded, as far as possible, against accidental or wilful injury by ships' anchors, fishing-nets and trawls. The most feasible mode of effecting this which has been yet proposed, is that of enclosing a gutta percha covered wire in a peculiar kind of chain or jointed cylinder of iron. The links are made somewhat like the joints of the vertebral column, so that they form a series readily flexible in every direction and yet perfectly enclosing the covered wire within. This chain or necklace would be laid along the bottom of the sea or river, and secured at various points by means of fixed moorings or anchors. The immense importance which would attach to some submarine lines of telegraph, is a guarantee, that although the scheme seems at present surrounded by difficulties, it will ere long be accomplished.

A method of crossing rivers or other small masses of water without the use of any wire, has been proposed, and found successful in some instances, but its applicability is limited to those few cases in which the width to be crossed is not very great, and the banks or margins of the water continue nearly parallel, for a distance considerably greater than their distance asunder. The proposition is based on the far greater resistance offered by water than by metal to the passage of the electric fluid. Referring to Fig. 825, it is obvious that if along the two banks of the river A B, insulated wires *cd*, *ef*, were carried for some distance, and their ends made to communicate with the water of the river, by plates or masses of metal sunk in the river, then a current sent from the battery at *d*, so as to pass along the wire to *c*, would, on arriving at the plate *c*, have two courses open to it, one being directly back through the water from *c* to *d*, and the other across from *c* to *e* along the wire *ef*, (passing through the instrument at *e*,) and back again from *f* to *d*. Now, it is found that if the two distances *c e* and *f d* be together much less than the distance *c d* or *e f*, then the resistance through the course *c e f d* will be so much less than that through the course *c d* of water, that the current will pass across the river at *c* through the wire on the other side, and again across at *f*, rather than take the direct water course *c d*. Or rather, strictly speaking, the current divides itself between the two courses in inverse ratio to their resistances, so that nearly all the current takes the circuitous course of least resistance, and very little takes the direct course of greatest resistance. The

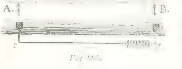


Fig. 825.

credit of this ingenious contrivance belongs to Professor Morse, of America.

The electric telegraph is at present in use in nearly all parts of the world; and many countries separated by the sea are connected by means of submarine cables. The various parts of the metropolis, and of large towns, are connected by Wheatstone's *Universal Telegraph*, which will be described in the Appendix, to which we must refer for further telegraphic details. Messages are transmitted at fixed rates for the accommodation of the public, in addition to the numerous communications made for the service of the several railways. The public messages are of course as varied in their subjects as the letters transmitted by post. Those for the railway companies comprise orders for the starting of engines and trains, notices of special trains, or of delays or accidents, orders to officers of the line, inquiries for luggage or for carriages, horses, beds, and refreshments. Of the extent and importance of these communications some idea may be formed from the fact, that in one year there were sent or received at the seven principal stations of one railway, upwards of 170,000 messages on railway business; and during the same period, one of these stations had despatched or received nearly 3,000 messages, entirely for the accommodation of the public.

Professor Wheatstone had shown by his beautiful investigations, before the construction of any telegraph, that the speed of electricity was quite equal to, and probably exceeded, that of light, which travels at 192,000 miles per second. There is therefore no time lost in the actual passage of a signal; for, taking the extreme range in Great Britain, that is, from Gosport to Glasgow, the signals are seen at one place at the same instant, sensibly, that they are made at the other. The actual time occupied in traversing the interval would be less than the 280th part of a second.

The actual speed of signalling varies much with different instruments. On an average it may be taken somewhat as under:—

	Words per minute.
Cooke and Wheatstone's double needle telegraph	35 to 42
Ditto. single needle telegraph	1[illegible] to 15
Bain's chemical printing telegraph	20 to 25
Commercial letter printing telegraph	7 to 15

These are the actual rates of working with experienced clerks. The time actually occupied in the passage of a message from the hands of the sender to those of the receiver, varies greatly according as its destination is on some main line of communication or on a second-rate branch line. In this last case the message will probably be sent first to the nearest main station, and be thence transmitted by the branch line. As these transmissions from one line to another may be (if the place of destination be some small and remote town) repeated two or three times, more time would elapse before the actual arrival of such a despatch than would be required for one addressed to a point of greater importance, and therefore of more direct communication.

The cost of a line of telegraph is dependent on so many circumstances that no precise data can be given. The number of wires, the mode of their suspension or insulation, the kind of timber used for posts, the number of stations, all concur to affect the cost. Generally, however, the cost of each wire is stated to be from 8*l.* to 10*l.* per mile, of the timber, posts, &c. from 10*l.* to 25*l.* per mile, and of each station introduced from 20*l.* to 30*l.* These amounts have reference to open line or suspended wires only, not to wires insulated for passage through tunnels or underground. [See APPENDIX.]

ELECTRO-METALLURGY. This important branch of modern industry (also called *galvano-plastic* or *electro-type*) owes its origin to the fact, that when a voltaic current is passed through a metallic solution, decomposition takes place; the metal in a revived form attaches itself to the negative pole or electrode, while the acid or alkali goes to the positive pole. Although this fact is nearly coeval with the discovery of the voltaic pile, yet it was not until about the year 1839, that it occurred to any one to turn it to practical account in electro-metallurgic processes. There would doubtless have been much difficulty in doing so before the invention of what is called the "constant battery;" but in this invention, and in the long inquiry which resulted therein, so many facts in electro-metallurgy were, as it were, thrust upon the inquirer, that nothing but the scientific preoccupation of the mind could have prevented the reception of the practical suggestions.[1]

The discovery of the voltaic pile was first announced by Volta, in a paper which he transmitted to the Royal Society in the year 1800. By means of this invaluable instrument, Nicholson effected the decomposition of water and of several metallic salts. Cruikshanks, the inventor of the galvanic battery, attached a silver wire to each pole of his battery, and placed the other ends of these wires in a glass tube containing a solution of acetate of lead: when the electric current had been made to pass through it for some time, metallic lead was found deposited on the negative pole. With solutions of sulphate of copper, nitrate of silver, &c., a similar result was obtained, the metals being in each case so completely revived as to suggest to Cruikshanks the application of the battery to the analysis of minerals. Many other scientific men, in this country and on the continent, made similar applications of voltaic electricity. Thus Brugnatelli gives a long list of experiments on the decomposition of salts by the pile. He observed the transfer of the elements of a decomposed compound from one pole to another; that silver when deposited upon platinum preserved all its metallic lustre, and that when copper or zinc was used in connexion with the positive pole of the pile for decomposing salts, these metals were dissolved and deposited upon

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(1) After several patents had been taken out, and the arts of electro-plating and electro-gilding were being profitably worked, the late Professor Daniell showed the Editor some of the first results of the constant battery, consisting of deposits of silver on some of the baser metals. "Ah!" said he, "I have let two or three fortunes slip through my fingers. I have had all the labour, and those Birmingham people are getting all the profit."

the negative pole. In 1805 this observer writes that he had *gilt* in a complete manner two large silver medals, by bringing them, by means of a steel wire, into communication with the negative pole of a voltaic pile, and keeping them one after the other immersed in ammoniuret of gold newly made and well saturated. Much earlier than this, viz. in 1801, Wollaston made the following observation—"If a piece of silver in connexion with a more positive metal be put into a solution of copper, the silver is coated over with the copper, which coating will stand the operation of burnishing."

These and a large number of similar observations were made by eminent chemists, and were published in journals and transactions, but for more than a quarter of a century they produced no fruits to the industrial arts. Even after the discovery of Daniell's constant battery, in which copper is being continually reduced upon the negative plate, it was observed that on stripping off this newly deposited copper, it had the counterparts of every scratch of the plate on which it was deposited; and yet this observation, frequently made, did not originate the art of electro-metallurgy. When, however, instead of the scratches on the negative plate being faithfully copied, a penny piece had been used by a self-taught man of genius, as the cheapest and readiest method of forming a negative plate, and the image and superscription of the coin had been copied in the deposited copper, as smoothly and as sharply as in the original, then the first perfect experiment in the art of electro-metallurgy had been made. But strange to say, even this beautiful and curious fact did not suggest to its discoverer (Mr Thomas Spencer, of Liverpool) any practical application; but having accidentally dropped some varnish upon a slip of copper which he was about to use in the same way as he had used the penny piece, and finding that no deposit of copper took place on the parts covered with varnish, he then conceived the idea of applying this process to the arts, by coating a piece of copper with varnish or wax, and cutting a design through it so as to leave the copper bare, and then to deposit a metal upon these parts, so that upon removing the varnish the design would be left in relief.

These experiments were made in 1837, but no account of them, or of the more successful results which were afterwards obtained, appears to have been published until September 1839. On the 4th May of that year, it was announced in the *Athenæum*, that Professor Jacobi at St. Petersburg had discovered a method of converting any line, however fine, engraved on copper, into a relief by a galvanic process. This announcement produced a letter from Mr C. J. Jordan, a printer, dated 22d May, and published on the 8th June of the same year in the Mechanics' Magazine. He describes his apparatus in the following terms:—"It consists of a glass tube closed at one extremity with a plug of plaster of Paris, and nearly filled with a solution of sulphate of copper: this tube and its contents are immersed in a solution of common salt. A plate of copper is placed in the first solution, and is connected, by means of a wire and solder, with a zinc plate which dips into the latter. A slow electric action is thus established through the pores of the plaster, the result of which is the precipitation of minutely crystallized copper on the plate of that metal, in a state of greater or less malleability, according to the slowness or rapidity with which it is deposited. In some experiments of this nature, on removing the copper thus formed, I remarked that the surface in contact with the plate equalled the latter in smoothness and polish. It occurred to me, therefore, that if the surface of the plate were engraved, an impression might be obtained. This was found to be the case; for on detaching the precipitated metal, the most delicate and superficial markings, from the fine particles of powder used in polishing, to the deeper touches of a needle or graver, exhibited their correspondent impressions in relief with great fidelity. It is, therefore, evident that this principle will admit of improvement, and that casts and moulds may be obtained from any form of copper. This rendered it probable that impressions may be obtained from those other metals having an electro negative relation to the zinc plate of the battery. With this view, a common printing type was substituted for the copper plate, and treated in the same manner. This also was successful: the reduced copper coated that portion of the type immersed in the solution. This when removed was found to be a perfect matrix, and might be employed for the purpose of casting, where time is not an object." Other practical applications are also pointed out, such as procuring copper dies from casts of coins or medals in silver, type-metal, or lead, &c., which may be employed in striking impressions in soft metals. "Casts may probably be obtained from a plaster surface surrounding a plate of copper: tubes or any small vessels may also be made by precipitating the metal around a wire, or any kind of surface to form the interior, which may be removed mechanically by the aid of an acid solvent or by heat." It is due to Mr Jordan, to state that these hints and suggestions made at this early period in the history of the art, have since been acted upon with considerable success, as will be presently seen.

We may wind up this historical notice by stating that the difficulty of obtaining copies in metal from plaster casts and similar non-conducting surfaces was completely overcome by the discovery of Mr. Robert Murray, that the use of plumbago or black-lead gave to the surface of non-metallic bodies a conducting property; so that it was no longer necessary to use metallic moulds, or moulds having metal reduced upon their surfaces by chemical means, which had hitherto proved the great barrier to the progress of the art.

In electro-metallurgy, the most important points to be considered are, 1, the *battery*; 2, the *moulds*.

THE BATTERY.—If a piece of zinc be put into a solution of sulphuric acid, a strong chemical action takes place; hydrogen gas arising from the decomposition of the water of the solution is evolved from the surface of the zinc, while the oxygen of the decomposed water unites with the metal, forming oxide of zinc, which is dissolved by the acid as fast as it is formed. If the zinc be amalgamated[1] there will be no action, for the mercury retains the zinc with sufficient force to protect it from the acid; but if a piece of copper be also immersed in the dilute acid, and the two metals be made to touch each other, as in Fig. 826, then the acid again acts upon the zinc, but the hydrogen now escapes from the surface of the copper, instead of the zinc: this action will be continued as long as the two metals are kept in contact, or have the means of communicating. Thus, it will be equally effectual if, instead of causing the two metals to touch, a copper wire be attached to each, and the opposite ends of the two wires be brought into contact, as at *x*, in Fig. 827. Or if the ends of the two wires be placed in dilute acid contained in another vessel, as in Fig. 828, the same action will take place between the zinc and the copper as if they were in contact, with this additional circumstance, that the ends of the two wires which dip into the dilute acid are also acted on: the wire attached to the zinc gives off hydrogen gas, while the one attached to the copper is rapidly dissolved. This second vessel in Fig. 828 is termed the *decomposition cell*.

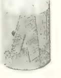
Fig. 826.

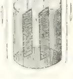

Fig. 827.

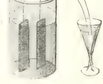
Fig. 828.

In the above arrangements we have a galvanic circle in its simplest form, of which the three parts or elements are zinc, acid, and copper, each of these bodies being in contact with the other, or connected therewith by conducting substances. Under these circumstances, a quantity of electricity is set in motion; a continued current of electricity passing from the zinc to the acid, from the acid to the copper, from the copper back again to the zinc, and so on in a constant circuit. By attaching wires to the plates, the circuit is lengthened, but the current moves in the same direction as before, viz. in the fluid from the zinc towards the copper, and along the wires from the copper to the zinc. The completion of the circuit by means of wires enables the operator to direct the electric current through bodies more or less distant from the battery, and it also enables him to interrupt or renew the communication between the two metallic plates, by merely separating or joining their remote extremities at *x*. When united, the wire *a*, Fig. 827, proceeding from the copper plate c, imparts electricity to the wire *b* in contact with the zinc plate z: so that the former is considered as being in a positive and the latter in a negative state.[2]

Almost any two metals with a liquid, arranged as in the above experiments, will produce an electric current; but the current will vary according to the kinds of metal employed, and the action of the liquid upon them. If the liquid act upon both metals, the current of electricity will be very feeble, depending, as it does, upon the difference between the action of the acid upon one metal compared with its action upon the other metal. If the liquid act equally upon both metals, there will be no electric current. The most effective electrical action is produced when the solution acts on one of the metals with great ease, and has little or no action on the other metal. The metal which is thus readily attacked or dissolved is termed the *positive*, and the other the *negative* metal. It must, however, be remembered, that metals are positive or negative to each other only when placed under similar circumstances. If a piece of copper and a piece of iron be connected, and immersed in very dilute acid, the iron will be dissolved, and hence is positive with respect to the copper; but if these metals be immersed in a solution of yellow hydro-sulphuret of potassium, the copper will be dissolved, and is hence + with respect to the iron. In the following list the common metals are arranged in the order of their relative negative and positive properties, when immersed in water acidulated with sulphuric or muriatic acid. At the head of the list is the most intensely negative metal, and at the bottom of the list is the most positive metal:—

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[1] The zinc used for a galvanic battery should be *rolled*, or rolled [illegible], and not thinner than one-eighth of an inch. The zinc plates may be amalgamated by first pickling them in dilute sulphuric acid (1 part acid + 8 parts water), contained in a stone-ware pan; when the plates are bright, pour a little mercury into the pan, then [illegible] at the end of a stick into the mercury, and rub it with [illegible] pressure on both sides of the zinc plate. The plate is next to be washed by dipping it into clean water, and then placed on its edge upon two small pieces of wood in another pan, to allow the mercury to drain from it. After draining for a few hours, the mercury may be rubbed again over the plate, and a second draining will complete the process.

Another method is to clean the plates by rubbing with [illegible], then immersing in dilute sulphuric acid, and then in water; the amalgamation is performed by dipping the plates into a mixture of [illegible] parts by [illegible] bichloride of mercury (corrosive sublimate) and acetate of lead; they are then rubbed with a cloth, and are ready for use.

[2] The terms *positive pole* and *negative pole*, as applied to the two extremities of the battery, have been objected to because, before connecting the two metals, or extremities of a battery, no electricity is evolved, and when the connexion is formed, the electricity simply makes a circuit, but it does not appear that one part of the circuit is more positive or negative than another part.

Dr. Faraday proposes to substitute for *pole* the word *electrode*, which signifies a *way*; for the negative pole *cathode*, signifying *the way down*, and for the positive pole *anode*, or *upway*. He supposes the battery to be lying on the ground, with its copper or [illegible] end to the east, and the wire connecting the ends of the battery to be bent into an arch similar to the course of the sun; in such case, the electric current will flow up from the east end of the battery, and descend into it at the west end. The body decomposed by a current passing through it is termed an *electrolyte*; the elements liberated by this decomposition are called *ions*; those liberated at the cathode are distinguished as *cathions*, and those set free at the anode as *anions*. Thus, when sulphate of copper is decomposed, the metal is the cation, and the acid the anion.

Professor Daniell used the word *platinode* for the negative and *zincode* for the positive pole.

Professor Graham uses the terms *zincous* and *chlorous* poles as synonymous with zincode and platinode, or + and −.

It is to be regretted that these strange and difficult terms should have been introduced, for they tend rather to confuse than assist the student. The old terms *positive* and *negative poles* and *electro-positive* and *electro-negative bodies*, are much more simple, and, in the present state of science, quite as accurate as the new terms.

Platinum.	Copper.
Gold.	Lead.
Antimony.	Iron.
Silver.	Tin.
Nickel.	Cadmium.
Bismuth.	Zinc.

In this arrangement, each metal is positive with respect to all that stand before it, and the electrical conditions become more marked the further apart they stand in the scale. Thus, a battery of zinc and platinum is very powerful, while one of copper and iron is very weak; but, as already stated, the chief condition of a galvanic battery is to obtain two metals, and immerse them in a solution which is capable of acting upon the one and not upon the other.

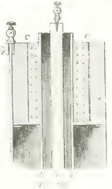
Copper and zinc are in many respects the cheapest and most effective metals. Some of the other metals, such as lead, are objectionable on account of the tendency to tarnish or oxidize: moreover, lead is a bad conductor of the electric current, and is hence not adapted to be used as an element in a battery, for the negative metal must be a good conductor (some say that it acts the part only of a conductor). The relative conducting power of the respective metals is as follows:—

Silver	120	Platinum	24
Copper	120	Iron	24
Gold	80	Tin	20
Zinc	40	Lead	12

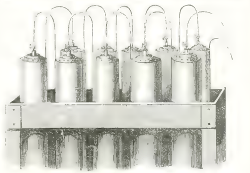
In any voltaic arrangement where the negative metal is not a good conductor, it should be placed very near to the other metal. It is not, however, necessary to describe the numerous forms of battery which had been contrived up to the date of the invention of the constant battery. They consisted for the most part of ten or twelve pairs of zinc and copper plates attached to a rod of wood, the zinc of one pair having metallic connexion with the copper of the next pair, and so on. The exciting liquid was contained in a trough divided into as many separate water-tight cells as there were pairs of plates attached to the rod. A wire attached to the last plate of zinc formed the positive pole, and a similar wire attached to the last plate of copper at the opposite end formed the negative pole. On bringing the two extremities of these wires together, the current was said to be closed. A number of these troughs properly connected together increased the effect in direct proportion. It was with such a battery, consisting of 2000 pairs, that Sir H. Davy decomposed the fixed alkalies, and made many other brilliant discoveries.

Now, the chief defects of such a battery are,—1. That the hydrogen evolved at the surface of the negative metal adheres with great force thereto, and greatly diminishes the effect by diminishing the acting surface. 2. A portion of the sulphate of zinc becomes in a short time reduced upon the copper, thereby weakening the electric current, and even producing a current in an opposite direction. 3. The copper also becomes coated with a thin, black, filmy layer of oxide and impurity, which also greatly diminishes the regularity and strength of the current. 4. Sulphate of zinc, formed by the action of the acid upon the zinc, gradually accumulates at the bottom of the cells, reacts upon the plates, and produces local currents, which greatly interfere with the principal current, which, of course, is alone practically useful. Indeed, this local action always took place more or less in the impure zinc of commerce, and was a great source of annoyance until the method of amalgamating the plates was introduced.

The above objections were happily removed by the discovery of the constant battery of Professor Daniell. The essential features of this battery are, the separation of the zinc from the copper by a porous diaphragm, such as bladder, unglazed porcelain, &c., and the use of two distinct fluids. That part of the battery which contains the zinc is charged with dilute sulphuric acid, and the part containing the copper is filled with a solution of sulphate of copper. The action of the battery is similar to that of the ordinary battery; the zinc is dissolved by the acid, but the hydrogen, instead of being evolved at the copper plate, combines with the oxygen of the sulphate of copper,[1] and the copper, thus set free from the acid, combines with the copper plate of the battery, thus keeping up a pure metallic surface during the evolution of a constant current of electricity, whence the term *constant battery* applied to this arrangement.



A cell of this battery consists of a cylinder of copper, Fig. 829, 3½ inches in diameter, and varying in depth according to the power required. A membranous tube, formed of the gullet of an ox, or a tube of porous earthenware, is hung in the centre by a collar, and a circular copper plate, resting upon a ledge, is placed near the top of the cylinder



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[1] Sulphate of copper is properly a sulphate of the oxide of copper. The copper must first be converted into an oxide before the sulphuric acid can dissolve it; the acid has no action on metallic copper, as such. The same remark applies to the sulphates of iron, zinc, &c.

in which is suspended by a wooden cross-bar a rod of amalgamated zinc half an inch in diameter. The cell is charged with a mixture of 8 parts water and 1 part sulphuric acid previously saturated with sulphate of copper, and crystals of the salt are placed upon the upper copper plate, which is perforated like a colander, in order to keep the solution always saturated. The internal tube is filled with the acid mixture without the sulphate of copper. A number of such cells may be easily connected by attaching the zinc of the one to the copper of the other, as shown in Fig. 830.

Admirable as this arrangement is, it has not been introduced in electro-metallurgic operations on a large scale, on account of the great quantity of blue vitriol required to keep it in working order, and from the inconvenience attending the use of porous diaphragms, which are soon destroyed by the action of the acid.

Mr. Grove's battery is the same in principle as the above, but differs in the arrangement of the metals and the exciting liquids, platinum being used instead of copper, and strong nitric acid instead of the solution of blue vitriol. A single cell may easily be fitted up in a jelly-pot or a tumbler. A cylinder of zinc is placed inside the vessel, within this is placed a porous vessel in which is a strip of platinum; the porous vessel is then filled with strong nitric acid, and the pot with dilute sulphuric acid; a wire attached to each metal completes the arrangement. When a series is used, Mr. Napier[1] recommends the zinc to be formed and placed in the cells of a trough, as in Fig. 831: the porous vessel, which should be flat,

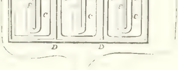

Fig. 831.

is placed within the zinc, Z, so that the platinum, P, contained in it may be connected with the zinc of the neighbouring pair at the top by means of binding-screws.

This form of battery has great activity of action and intensity or power of current. A battery consisting of three pairs of zinc and platinum is more effective than an ordinary battery of ten or twelve pairs. The porous cells are not so soon closed up by the deposition of metals upon or within them as in Daniell's battery; but it has not the constancy and steadiness of the latter arrangement, and, moreover, it emits corrosive nitrous acid fumes, an objection which will probably prevent it from being employed by the manufacturer.

One of the cheapest and most convenient forms of battery is that contrived by Mr. Alfred Smee. This gentleman had observed that if the copper plate of a battery be roughened either by the use of corrosive acids or by rubbing with sand-paper, it will throw off the hydrogen much more freely than the smooth one. He therefore made platinum foil rough by covering it with a finely-divided black powder of platinum, deposited by electricity from a solution of that metal, and used this instead of the copper in the ordinary battery. A plate of platinized silver is now more economically used, and is placed between two plates of zinc, Z Z, as in Fig. 832, which represents a single cell, a being the jar containing the solution of dilute sulphuric acid, and s the platinized silver plate. The two plates of zinc are separated by a cross-bar of wood, and in order to preserve the plates parallel to each other, which is essential, the wooden frame is notched round the edge of the thin silver plate. One of the clamps, at the top of the wooden bar, is connected with the platinized silver plate, and the other with the zinc pair. This form of battery is much used by amateur electrotypists, but not to any great extent in factory operations.

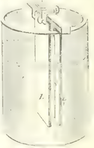

Fig. 832.

THE MOULDS.—In copying objects by the process of electrotyping, it is of the first importance to be able to prepare good moulds or reversed copies of such objects, wherein to deposit the metal by electrical action. The moulds may be made of fusible metal, wax, stearine, gutta percha, and a composition into which spermaceti largely enters.

Fusible metal has already been described in the article ALLOY (p. 38, *ante*). The proportion of the ingredients in a pound of this alloy is, bismuth 8 oz., tin 3 oz., and lead 5 oz. These should be melted together in a clean iron ladle, and as soon as they are completely liquefied, be poured on a stone slab in drops; then re-melted in the ladle, and poured out a second and a third time, to ensure the combination of the ingredients. The medal to be copied must be brushed over with a little sweet oil, and carefully wiped with a piece of cotton wool. A slip of cardboard or tin is next to be bound round the edge of the medal, the edge of the slip rising about a quarter of an inch above the highest part of the face of the medal. The fusible alloy is to be poured in a melted state into a small wooden tray, and just as it is on the point of solidifying, the medal, with the face downwards, is to be suddenly brought down upon it, and held until the alloy has fairly set. When it is cold, the slip around the medal is to be removed, and the mould will easily separate, its thickness being determined by the height of the slip. A film of oxide is apt to form on the mould, which will render the cast dull. Mr. Walker remarks that "dull-looking moulds must always be rejected, for so minutely correct is the process of electrotype, that the dulness of the mould will be transferred to every copy made from it. Even if an original medal be incautiously handled, the slight trace of a finger-mark will be transferred to the mould, and thence to the electrotype copies."

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[1] Mr. James Napier's excellent little "Manual of Electro-Metallurgy," published at a cheap rate [illegible] in Mr. Griffin's new edition of the [illegible] Metropolitana, ought to be in the hands of every [illegible] electrotype operations. Mr. Walker's [illegible] little volume on "Electrotype Manipulation," the first part of which has reached the 29th edition, and the second part the 18th, [illegible]. Both of these works have been of much help in the preparation of this article. We must also refer to the following works of authority:—

"Elements of Electro-Metallurgy," by Alfred Smee, F.R.S. Second Edition. London, [illegible].

"A Manual of Electro-Metallurgy," by George Shaw. Second Edition. London and Birmingham, [illegible].

A fusible alloy containing antimony is used for obtaining the beautiful casts of the French medals, which are so much admired. The composition is, bismuth 8 parts, tin 4, lead 5, and antimony 1. The medal to be copied is to be mounted in the cavity of a block of wood shaped like a button-die, and the metal being poured into a shallow box lined with smooth cartridge-paper, any film of oxide upon it must be swept off with a card, and just as the metal is on the point of solidifying, the medal should be struck gently and steadily upon it. *Clichée* moulds thus formed are very perfect.

Bees'-wax, with or without stearine, is to be melted in a pipkin over a slow fire, and about one-sixteenth of white-lead or flake-white stirred in: the mixture should be melted two or three times before using it for the first time. The medal must be prepared as above directed, and then held with its rim a little sloping: the wax, just as it is beginning to set, is then to be poured into the lowest portion, and gently brought to a level, so that the wax may flow over the whole: this will prevent the formation of air-bubbles. As soon as the wax has solidified, the card rim must be removed, for, if allowed to remain until the wax has become cold, the wax will adhere to it, and, being prevented from shrinking, would be liable to crack. In the course of an hour or two, the wax will easily separate from the mould.

Plaster of Paris moulds are formed by making the finest plaster into a thick cream, and pouring a small portion of it upon the face of the medal, and then with a small brush gently brushing the plaster into every part of the surface: this will prevent the formation of air-bubbles: the remainder of the plaster is to be poured in until it rises to the edge of the rim. In about an hour the mould may be taken off and dried before the fire, after which it is to be placed back downwards in a shallow vessel containing melted wax, not sufficiently deep to cover the face of the mould, but the vessel being put over a slow fire, the wax will penetrate the plaster and appear on the face. It is then removed, and left to harden in a cool place.

Gutta percha is well suited for making moulds. This substance must be made soft and pliable by being heated in boiling water or in air at that temperature: the medal must be fitted with a metallic rim, and a quantity of the softened gutta percha forced upon it until it stands above the edge of the rim: it is then placed in a common copying press, and kept under pressure until it is quite cold and hard. The impressions taken in this way are usually very fine, all the deep parts being represented in a manner superior to those taken in wax.

Wax moulds may be taken from plaster moulds by saturating the latter with boiled linseed oil or even with water or skimmed milk. A mould of plaster from a plaster medal may also be taken by wiping the medal with a little soft soap and tallow, or wetting it with a solution of soap. Fusible alloy moulds may also be taken from plaster by similar contrivances.

In order to give the non-metallic moulds a conducting surface, black-lead is applied to them, as already noticed: a copper wire is first put round the edge of the mould; or if of wax, a thin slip of copper is inserted into its edge; or if the copper be gently heated and laid upon the back, the wax will adhere to it. A fine brush, such as a small hat-brush, is then dipped into fine black-lead, and brushed over the surface of the medal until the whole face has a complete metallic lustre. None of the black-lead must be allowed to get to the back of the mould, or to any part where a copper deposit is not required. When the mould appears to be covered, no whitish spots should be seen on breathing upon it: if such spots do appear, the brushing must be continued.

In some cases the black-lead may be applied wet, and then be polished. Some operators use a mixture of powdered zinc and plumbago: the zinc is prepared by melting it in an iron ladle until it is near the point of burning, when a few pieces of iron are dropped into it: when cold this mixture is very friable. In large moulds, guiding wires have been found useful in addition to the coating of plumbago. These wires are twisted round the main wire, and their ends are allowed to rest against different parts of the mould, especially in the recesses of deep relief. When the copper is deposited the wires are carefully removed. Delicate objects, such as flowers, insects, &c., which would be injured by brushing are prepared by dipping them into a weak solution of nitrate of silver, and reducing the silver by exposure to vapour of phosphorus, or by the action of light, or by sulphurous acid gas. In this way the surfaces of the most delicate objects are made conducting.

Single Cell System.—The previous detail respecting the formation of a voltaic battery will enable us readily to understand, that if one of the moulds prepared as above directed be attached to one end of a wire, and a piece of zinc be fastened to the other end of the wire, and the zinc be immersed in dilute acid, and the mould in a solution of sulphate of copper, the two liquids being separated by a porous partition, the electric current expends itself in depositing the metal on the mould. In fact, the mould takes the place of the copper plate in the voltaic battery. Now, it occurred to Mr Mason that the electricity generated in the *decomposition* cell might be made to do an equivalent of work in a separate cell, making the arrangement just described the *generating* cell, or battery to the second cell. In other words, a mould in the act of being filled was made to serve as part of a battery to another mould also in the act of being filled. The arrangement is shown in Fig. 833, r which v′ is a vessel containing a solution of sulphate of copper; v another vessel, in which is P, a porous cell, filled with dilute acid, in which is placed z, a zinc plate, connected by a wire with the medal *m′* in the second vessel charged with sulphate of copper. The medal *m* in the first cell is connected by a wire with a piece of copper c in the second cell. The electricity passes from the zinc *z* to *m*, and by the wire to c; then to *m′*, and by the wire back to the zinc z.

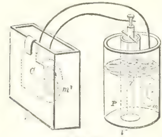

Fig. 833.

The usual form of the single cell apparatus is shown in Fig. 834, in which z is a rod of amalgamated zinc, *m* the mould, *w* the wire joining them, c the solution of sulphate of copper, *t* a tube of porous earthenware, containing the acid solution. Fig. 835 is another form of this apparatus, in which the zinc is connected, by a wire and binding-screws, with a metal rim, and on the latter are hung several moulds attached to wires. The process is more likely to succeed when several moulds are being operated upon at the same time. The copper solution must be kept saturated by having the perforated shelf supplied with crystals.

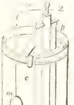

Fig. 834.

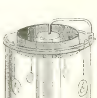
Fig. 835.

Compound Cell System.—This method of economizing power will be understood from Fig. 836, in which A is a Smee's battery, z the wire conducting electricity to the compound trough, which is composed of a series of water-tight cells, and is connected with a piece of copper c, forming a positive electrode; in the same cell, and facing this electrode, is a medal connected by a copper wire to a piece of copper placed in the second cell, opposite to which is another medal connected in the same manner with another piece of copper, and so on throughout the series, which terminates with a medal attached to the wire of the battery. The electricity from the battery passes through all these cells, and reduces its equivalent in each cell. Thus the solution of 32 grains of zinc in the battery, would deposit 32 grains of copper multiplied by 6 times, or as many times as there are cells. It must, however, be remembered that every cell adds so much to the resistance of the current, that a battery of considerable power is required. Thus to work the above arrangement, a battery of 6 pairs of plates would be required to give sufficient intensity to overcome the resistance, and the same number of medals could be made of the same weight by 6 separate zincs, and in less than half the time in which they could be made by this arrangement, and with a less expenditure of zinc.

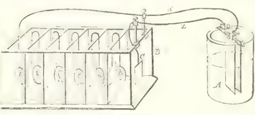

Fig. 836.

The copper solution used for obtaining the deposit acts differently upon different moulds. If a mould of fusible metal be placed in the solution before the battery is in action, it will act chemically upon it, and produce on its surface a dark dirty deposit. Hence the battery must be got ready, and then the circuit be completed by immersing the mould last. In such case, a very poor deposit of copper is instantly made on its whole surface, and the mould is not even wetted by the liquid. When a sufficient thickness has been deposited, the copy is removed and the mould can be used again. The deposit of copper on the plumbago surface of a wax mould, is not instantaneous, but gradual; commencing near the wire attached to it, and gradually spreading over the surface. When the deposit is removed, it carries off with it the whole or a portion of the plumbago, so that the moulds require a fresh coat of this substance before they can be used again. If all the arrangements have been properly made, the deposit of copper will be of a brilliant light colour. Beginners in the art are often annoyed at the rotten character of their deposits. This was formerly supposed to result from the presence of sulphate of zinc with the sulphate of copper. "The real cause depends on the relation subsisting between the generating power dependent on the action between the zinc and the acid, and the strength of the solution of the sulphate of copper, on which this power is exercised. If the latter be well saturated, the copper will be released pure and firm: if it be almost exhausted, the hydrogen gas will be released from the copper, and the deposit will be a dull powder. In the wide range between these two states is found the brittle deposit: it appears under many varieties of forms, according as the solution is nearer to a state of saturation or to one of exhaustion, on the one hand; or according to the energy or weakness of the affinity between the zinc and its exciting solution, on the other. This latter condition exists in a modified form, when a large piece of zinc is used with a small object to be copied. The deposit is very hard, but not tenacious. It may be easily broken. In copying seals and such like small objects, pieces of zinc an inch square are quite large enough."

The medals may be removed from the moulds of fusible metal by gently and carefully raising the edges with a brad-awl. The separation from the wax mould may be accomplished by laying it on a flat surface, face downwards, and after pressing in different parts of the circumference the slight overlapping edge of copper with the brad-awl, the two may be pulled apart.

The electrotype medals may be bronzed brown by wetting them with a solution formed by adding four or five drops of nitric acid to a wine-glassful of water: when the medals are dry, they should be gradually heated. A very dark coloured bronze may be given by washing with a solution of sulphuret of ammonia, drying at a gentle heat, and polishing with a hard hair-brush. A green bronze may be imparted by steeping the medals for some days in a strong solution of common salt, or by exposing the medals to the fumes of vinegar or muriatic acid. The appearance of the ancient green bronze may be given by suspending the medals over a very small portion of bleaching powder, contained in a small covered jar. [See APPENDIX.]

OTHER APPLICATIONS OF THE ART.—In addition to the copying of medals and other similar works, many useful applications of electrotyping have been made, such as imparting a *coating* of copper to *cornices* for decorating buildings, to *terra cotta, wood carvings*, &c. *Cloth* has also been covered and made to appear like a sheet of copper, while it retained the lightness and pliability of cloth. *Lace* has been covered with copper, and even gilt, and made into beautiful ornaments. *Table covers* with metallic ornaments richly gilt, and *book covers*, have also been prepared by this art. Attempts have been made to prepare and etch *calico printer's rollers* by this process, which has been successfully applied to many of the operations of ordinary printing. It has been used in the production of *music printing plates*, and for raising surfaces for *embossing* soft materials such as leather; by depositing a sheet of copper upon a skin of morocco leather, it can be used for imparting an impression to other skins. Mr. Palmer has also applied the electrotype to the art of *engraving*. The principle of the invention consists in depositing copper in the grooves or engravings, made in a layer of some soft substance spread on a sheet of copper, and covering the whole with a sheet of electrotype copper. The counterpart of the engraving thus produced, is used in printing in the same manner as wood-blocks; that is, they can be made up with the type, and printed from at the ordinary printer's press.[1] *Copper-plate engravings* have also been copied by this art: an electrotype mould is first made of the engraving, and from this any number of electrotype copies of the copper-plate engraving may be successively deposited. These plates are, however, so rapidly worn away in the ordinary process of copper-plate printing, that the old method of steel-engraving is preferable to this new one. *Daguerreotype pictures* have been electrotyped in the following manner:—a piece of cleaned flattened wire is soldered to the back of the picture, which is then protected by wax, and put into the copper solution in the same manner as a medal; when the deposit is sufficiently thick, it may be separated easily, and will be found to be an accurate copy of the original, with even a softer and finer expression: several electrotypes may be taken from one picture. The electrotypes may next be passed through a weak solution of cyanide of gold and potassium, and subjected to the action of a very feeble current, when a beautiful golden tint will be given to the picture, which will protect it from the action of the atmosphere; it should also be protected by a glass.

A process has lately been proposed, under the name of *Galvanic soldering*, by which two pieces of metal may be united by means of another metal deposited therein through the agency of a voltaic current. Mr. Elsner has described in the Mining Journal some successful experiments on this subject. In one of these, a strong ring of sheet copper was cut asunder at one point, and a space of about $\frac{1}{8}$th of an inch left between the severed parts. This ring was then attached to the negative electrode of a constant battery, when, after a few days in the copper solution, the space in the ring was completely filled up with solid coherent copper. In another experiment, two strong rings of sheet copper were laid with their freshly cut faces one upon the other, so as to form a cylinder; the rings were surrounded with a band of tinned iron, coated with a solution of wax, and were thus attached to the negative wire of the battery, and immersed in the bath of sulphate of copper. At the end of a few days, the interior surface of the rings was covered with precipitated copper, and between the contact surfaces, copper was also precipitated. The rings had only been submitted to the voltaic current to such an extent as to cover their interior surface with a thin coating of copper, but they were completely re-united and formed a cylinder of a single piece.

ELECTRO-PLATING.—We have noticed the applications of electrotype to the coating of surfaces with copper. We come now to notice briefly the extension of the art to the production of plated goods, or the deposit of silver upon a baser metal, such as copper, brass, and German silver, which are best adapted for the purpose.[2] Instead of the solution of sulphate of copper, used for obtaining the copper precipitate, a solution of cyanide of silver, dissolved in cyanide of potassium, has been found best adapted for obtaining the silver precipitate. This solution is usually obtained by dissolving metallic silver in dilute nitric acid, heated in a proper vessel, placed under a hood, so that the deleterious nitrous fumes may escape. When the metal is dissolved, the solution is removed to a large vessel and diluted with water, to which is added a solution of cyanide of potassium, until a white precipitate of cyanide of silver ceases to be formed. The action that ensues may be thus represented:—

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[1] The reader interested in this subject is referred to a pamphlet, published in 1844, entitled 'Glyphography, or Engraved Drawing for printing at the Type Press, after the manner of Wood-cuts.'

[2] Iron, zinc, tin, pewter, and Britannia metal, are not easily plated by the electrotype. Lead is easily plated, but it tarnishes readily, and is too soft for the operations of the burnisher.

SUBSTANCES EMPLOYED.		SUBSTANCES PRODUCED.	
Nitrate of silver ...	AgO, NO_5	Nitrate of potash	KO, NO_5
Cyanide of potassium ...	KCy	Cyanide of silver	$AgCy$

When the precipitate has settled, the clean solution is carefully decanted off, and the vessel filled up with water, which is again decanted when the precipitate has settled. This is repeated three or four times, in order to dissolve out the soluble salts. A solution of cyanide of potassium is then added to the precipitate until it is all dissolved. This solution having been filtered, forms the plating solution, and consists of cyanide of potassium and silver. There are various other solutions of silver in use, such as cyanide of silver dissolved in yellow prussiate of potash; hyposulphite of silver solution; a solution made with chloride of silver, and others, which are described in Mr. Napier's treatise.

The articles to be plated are cleansed from grease by being boiled in an alkaline ley; they are then washed, and dipped into dilute nitric acid, which removes any oxide that may have formed on the surface; they are next brushed with a hard brush and Isle of Wight sand. Each article to be plated being thoroughly cleansed, is suspended by twisting a copper wire round it, or by putting the wire through any open part. It is then dipped quickly into nitric acid, washed through water, and immersed in the silver solution, by suspending it from the wire which crosses the mouth of the vessel from the zinc of the battery. The article becomes instantly coated with silver, and after a few seconds is taken out and well brushed with a hard hair-brush and a little fine sand; or on a large scale, brushes of brass wire, attached to a lathe, are used for the purpose. This brushing removes any particle of foreign matter which might prevent the perfect adhesion of the silver precipitate. It is replaced in the solution, and in the course of a few hours a coating of the thickness of tissue paper is deposited on it, having the beautiful matted appearance of dead silver. If this appearance is intended to be preserved, the article must be carefully taken out and immersed for a few minutes in boiling distilled water. On being removed, it dries instantly. "If it is a medal, it ought to be put in an air-tight frame immediately;[1] or if a figure, it may be at once placed under a glass shade, as a very few days' exposure to the air tarnishes it by the formation of a sulphuret of silver, and that more especially in a room were there is fire or gas. If the article is not wanted to have a *dead* surface, it is brushed with a wire brush and old ale or beer, but the amateur may use a hard brush and whiting. It may be afterwards burnished according to the usual method of burnishing, by rubbing the surface with considerable pressure with polished steel, or the mineral termed *blood stone*. We may remark, that in depositing silver from the solution, a weak battery may be used; though, when the battery is weak, the silver deposited is soft, but if used as strong as the solution will allow, say 8 or 9 pairs, the silver will be equal in hardness to rolled or hammered silver. If the battery is stronger than the solution will stand, or the article be very small compared to the size of the plate of silver forming the positive electrode, the silver will be deposited as a powder."

The battery must be so arranged that the *quantity* of electricity generated shall be sufficient to give the required coating of metal in a given time, and the *intensity* sufficient to cause the electricity to pass through the solution to the articles. The plates of metal forming the positive pole in the solution should correspond in surface to the articles to be coated, and face them on both sides. In some of the large factories, the *vat*, or plating vessel V, Fig. 837, is about 6½ feet long, 33 inches broad, and 33 inches deep, and contains generally from 200 to 250 gallons of solution. The silver plates which are used as electrodes are fixed upon light iron frames. Two battery-troughs, consisting of 6 batteries of 3 pair intensity, are arranged as in the figure. The zinc plates immersed in the acid are each 6 inches by 7, or 84 sq. in. of exposed surface: thus giving for the 6 plates 504 sq. in. from which electricity is disengaged. The surfaces of the silver electrodes exposed to the articles receiving the deposit vary from 3,000 to 4,000 square inches of surface. In the battery B, the zinc pole Z is connected with the rods R R, and the copper pole C is connected with the metallic sheets P P in the solution, by means of the copper slip F. D D are articles suspended in the solution by wires from the rods R R. As soon as the articles, which are connected with the negative pole of the battery, and the metallic sheets connected with the positive pole, are both immersed in the solution, the voltaic circuit is completed. The amount of metal deposited is ascertained by weighing the articles before and after plating, making an allowance for the loss occasioned by the dipping into nitric acid, which Mr. Napier states will cause an average loss of about one pennyweight upon an article of the size of a foot square. Any thickness of silver may be given

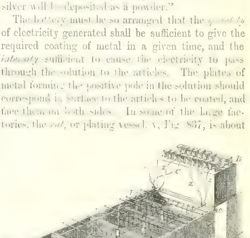

Fig. 837.

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(1) "For ordinary purposes, medals may be very conveniently protected by cutting a piece of common glass over the surface, cut to the exact size, and held close by a strip of paper pasted round the edges of both, and then a stout piece on the back."

[illegible] by [illegible] the operation [illegible] [illegible]. A [illegible] found to show [illegible] [illegible] [illegible] as [illegible] writing-paper.

There is a tendency in the [illegible] solution to [illegible] itself into layers of unequal density, the consequence of which is, that an unequal deposit is made upon the articles, more being laid upon the lower parts than upon the upper. This is prevented by keeping the articles in motion, for which purpose, in some factories, some simple machinery is attached to the vat, and moved by the engine power or by clockwork. Care must be taken that the voltaic current is not stopped while the deposit is being made, otherwise the metal deposit will be rapidly dissolved off. Keeping the articles in motion also remedies another defect, viz. the formation of porous silver. All deposited metal is crystalline, but Mr. Napier states that, by [illegible] and proper management of the battery, he has deposited silver of as high specific gravity as [illegible] silver. [illegible] [illegible] gives [illegible] to the [illegible] [illegible] that they may be more easily burnished.

When the deposit is judged to be sufficiently thick, the articles are taken out of the solution, dipped in water, then put into boiling water, and afterwards dried in hot sawdust. Their colour is [illegible]. After being weighed, they are brushed with fine wire brushes and stale beer, as already described, which changes the appearance of chalk white into that of bright metallic silver. The chalky appearance may be prevented, and the deposit be made to have that of bright metallic silver, in the first instance, by adding to the solution a small quantity of sulphuret of carbon.

Solid silver articles may be formed by the electro process, by first making a copper mould by the electrotype, and depositing the silver within it to the proper thickness. It is then kept in a hot solution of crocus and muriatic acid, or boiled in dilute muriatic acid, which dissolves the copper without injuring the silver. An objection to solid silver articles is, that they are *dumb;* that is, they will not *ring* on being struck or placed suddenly upon a table, as standard or alloyed silver does, but appear to be cracked, or like lead. This arises from the crystalline character of the silver, and also from its purity, for the sound is not improved by beating and hammering. The same objection applies to gold deposited by electricity. [See APPENDIX.]

ELECTRO-GILDING.—The gold solution is formed by dissolving gold in nitro-muriatic acid, so as to form chloride of gold. This is digested with calcined magnesia, and the gold is precipitated as an oxide: the oxide, having been boiled in strong nitric acid, which dissolves any remaining [illegible], is well washed, and dissolved in cyanide of potassium, which gives cyanide of gold and potassium. In using the cyanide solution, a temperature of at least 130° Fahr. is necessary. The positive electrode of the battery must [illegible] [illegible] [illegible] [illegible] [illegible]. A small [illegible] may be [illegible] gilt in three or four minutes. Iron, tin, and lead are very difficult to gild; but by first depositing a thin coating of copper upon them, the gilding is readily performed. "The gilding solution generally contains from one-half to an ounce of gold in the gallon, but for covering small articles, such as medals, for tingeing daguerreotypes, gilding rings, thimbles, &c., a weaker solution will do. The solution should be sufficient in quantity to gild the articles at once, so that it should not have to be done bit by bit; for when there is a part in the solution and a part out, there will generally be a line mark at the point touching the surface of the solution. The [illegible], with water, makes [illegible] [illegible] the surface [illegible] of the solution is [illegible]. If the positive electrode is not wholly immersed in the solution, it will, in a short time, be cut through at the [illegible] of the solution, as if cut by a knife. This is also the case in [illegible] other solutions. . . . According to the amount of gold deposited, so will be its durability: a few grains will serve to give a gold *colour* to a very large surface, but it will not last: this proves, however, that the process may be used for the most inferior quality of gilding. Gold thinly laid upon silver will be of a light colour because of the property of gold to transmit light. The solution for gilding silver should be made very hot, but for copper it should be [illegible] heat. A mere blush may be sufficient for articles not subjected to wear; but on watch-cases, pencil-cases, chains, and the like, a good coating should be given. An ordinary-sized watch-case should have from 20 grains to a pennyweight: a mere colouring will be sufficient for the inside, but the outside should have as much as possible. A watch-case thus gilt, for ordinary wear, will last five or six years without becoming bare. We have known some to be in use full six years without losing their covering. Small silver chains, such as those sold at 8*s*., should have 12 grains; pencil-cases of ordinary size should have from 3 to 5 grains; a thimble from 1 to 2 grains."—*Napier.*

Among the applications of electro-gilding may be mentioned the gilding of springs and works of chronometers. M. Perrot has undertaken to gild all the movements of a watch not only while in their places, but also while in motion. M. Hamman, an engraver, has deposited a coat of gold instead of one of varnish on plates intended for ordinary etching, and has traced the design through this delicate layer.

The cyanogen gas given off from the cyanide solution appears to have an injurious effect on the health, especially in badly ventilated workshops. The hands of the people engaged in plating and gilding are also subject to ulceration, and the ulcers are difficult to heal. Eruptions, also in some cases, will break out over the body of the workman, in consequence of inhaling the deleterious fumes.

Electro-Zincing, &c.—Iron can be covered by zinc, and thus be protected from rust, by the electro-process, the solution being that of sulphate of zinc, and the battery one of feeble power. Another method of making this *galvanized iron* is given in the article Amalgam, page 43. Recipes have also been given for *electro-tinning* and *electro-brassing*. Patents have also been taken out for processes for reducing copper from its ore by the aid of an electric current. There are also various other applications of the art of electrotype, but time is required to test their value.

Statistics.—Birmingham is the chief seat of the electro-plating and gilding trade, and Messrs. Elkington and Mason's factory is the most important one. The Editor visited this factory a few years ago, and saw the practical application of the art on a large scale. By its means a revolution has been effected in the plating trade. It was introduced by Mr. Elkington, in 1840, amidst much discouragement and opposition. Manufacturers and retail tradesmen were opposed to the change. "All sorts of objections were started, and the silversmiths refused, in many instances, to take the articles into their shops, even to retail them at a profit. But these and innumerable other difficulties were ultimately powerless to obstruct the progress of the art. The wonderful nature of the agency by which the result was effected excited curiosity; but when it was seen that the operation was so simple and so unerring—that the most elaborate articles could be plated with as much perfection as a common sheet of metal—and that for beauty and elegance electro-plated goods were fully equal to articles chased in solid silver or gold, a demand for them began to arise. As early as 1841 the business had assumed considerable importance, and in the year 1842 the Messrs. Elkington found constant employment for as many as 300 people. The manufacture has since gone on increasing, and the patentees now employ upwards of 500 hands; they are extending their works, and the manufacturers in Birmingham and Sheffield, licensed by them to use their patent, amount to upwards of thirty, of whom those resident in Birmingham are supposed to employ from 300 to 400 persons, in addition to those on their own premises. The principal advantages of the electro-plated goods are that they are manufactured in the same manner as silver, the ornamental parts being chased in solid metal, and that, where joints are necessary, none but hard solder is used; that the base is composed of a purified white nickel metal, of great durability, and of the same colour as the exterior; that the union of the surface and base is perfect, forming one body; that the plating on the more prominent parts is, from the nature of the process, stronger than on those parts less exposed to wear; that every description of style, however elaborate, and whether embossed or engraved, can be plated with the same facility as a plain surface; that with moderate care these goods will last from ten to twenty years, and that they can be replated when injured or worn (which, under the old processes, could not be done), at a comparatively trifling expense.

"The show-rooms of Messrs. Elkington and Mason contain specimens not only of electro-plated articles, such as *epergnes*, candlesticks, candelabra, vases, and countless other objects of domestic use and adornment, of modern and of antique art, but of new adaptations of the electro-process to the service of the sciences. They exhibit beautiful specimens of the vegetation or growth of copper by electrical agency; of iron coated with zinc or copper; of flowers and shrubs, with all their delicate anatomy and tracery, coated with metal, and thereby rendered imperishable; and of birds and insects coated and preserved by the same wonderful but simple means. Leaves and flowers of gold and silver are thus manufactured, nature being made to form the basis of art in a manner hitherto unknown. Flowers and shrubs, insects, and other natural objects which it is wished to preserve, are coated with zinc, copper, silver, or gold. Where the coating is of the less valuable metals, it may be painted of the colour of nature; and the specimens by this means may be preserved for centuries. So delicate is the operation of the electric current that even a spider's web may be plated with gold or silver.

"The workmen employed in this beautiful manufacture are, as might be expected, of a superior class. It was remarked by an intelligent manufacturer in another branch of trade, that he always found men who worked by mere manual labour, and with ordinary tools, inferior to those who made use of steam power. The complicated machinery and the regularity of steam power tended, he thought, to make the men regular as well as intelligent. The electro-process seems to have exercised a similar, if not a higher, influence upon the character of the workpeople. From an examination of the time-book of Messrs. Elkington, it appears that out of the 500 persons in their employ, not two, on the average, were absent on any Monday, or on any part of a Monday, during the year—a fact very remarkable in Birmingham, where the working classes make it a constant practice to neglect their work on that day, and where it is a common complaint among employers, especially when trade is brisk, that men sacrifice not only the Monday, but too often a portion of the Tuesday, to drinking and idleness. Ten years ago the platers are represented as having been 'a rough set,' but those employed in the superior branches necessary for the finer beauty of the electro-process, bear the highest character, not only for regularity and sobriety, but for their provident economy. Great numbers of them save money. They have no union of the trade, but they have founded a sick and burial club, and have it in contemplation, in conjunction with their employers, to establish a school for their children and for the boys engaged in the manufacture, and a library and reading room for themselves. It is to be hoped that no circumstances will arise to prevent the realization of a design in every respect so praiseworthy." [1]

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(1) Correspondent of the Morning Chronicle

ELECTRO-MOTIVE MACHINES AND MAGNETO-ELECTRIC MACHINES. It is proposed in the present article to bring together, first, a few details respecting voltaic electricity as a source of motive power, and, secondly, to state the conditions under which the magnet may be made to supersede the voltaic battery in the art of electro-plating and gilding, &c. Although these two subjects are not very intimately connected, yet they have a common tie, and will be of more interest as associated with the articles on the ELECTRIC TELEGRAPH and ELECTRO-METALLURGY than if deferred.

The property of a voltaic current to convert soft iron into a magnet, and the disappearance of the excited magnetism the moment its action is suspended, have already been noticed. (See ELECTRIC TELEGRAPH.) This property has placed at command a very considerable force, which has been applied by ingenious men as a moving power. Up to the present time no great success has attended the production of electro-magnetic machines, and it will always be a serious question, whether the zinc fuel which is burnt to produce electricity is not more costly than the coal fuel which is used to produce steam in the steam-engine. It certainly does appear to be a circuitous process, first to burn our coal in order to smelt our zinc ore, and then to use the zinc as a fuel for producing power.

The general principles observed in the construction of electro-magnetic engines are, to produce a rapid change of polarity in masses of iron, surrounded by spiral coils of insulated wire, so as to cause them alternately to attract and repel other electro-magnets brought within their influence; or masses of iron are rapidly magnetized and demagnetized without change of polarity, by which means an attractive force is exerted upon other masses of iron so long as the attraction pulls them onward in one direction and no longer. In either case a rotatory motion is obtained by fixing the masses of iron on the circumference of a wheel, and placing the wheel so as to allow the electro-magnets to act upon the extremities of its radii, as is practised in the application of moving force to the circumference of a wheel.

By means of an engine on this principle, Professor Jacobi, of St Petersburgh, in 1838 and 1839, succeeded in propelling a boat upon the Neva at the rate of four miles an hour. The boat was 28 feet long, about 7 feet wide, and drew nearly 3 feet of water. It contained ten persons. The engine was worked by a voltaic battery of 64 pairs of plates, and it propelled the vessel through the medium of paddle-wheels. In 1848 Mr Llewelyn exhibited to the members of the British Association a similar experiment on a lake at his residence near Swansea. A small boat was propelled with considerable force by means of a screw, worked by an electro-magnetic engine. Jacobi applied his engine to the working of machinery, but not with any great success. In 1842 Mr Davidson constructed an electro-magnetic locomotive engine, which was tried on the Edinburgh and Glasgow Railway; the carriage was 16 feet long and 6 feet wide, and, including the batteries and magnets, weighed above five tons. It was propelled at the rate of about four miles an hour.

Various forms of electro-magnetic machines have been invented by Wheatstone, Talbot, Hearder, Hjorth, and others, but it is not likely that such machines will meet with much encouragement while coal, the food of the steam-engine, is abundant. That a great force may be commanded is evident from the fact, that an electro-magnet lately exhibited in London attracted a mass of iron at ⅛th inch distance with a force of 1341 lbs., and it required

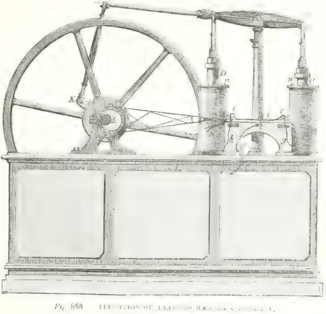

Fig. 898.—ELEVATION OF ELECTRO-MAGNETIC ENGINE.

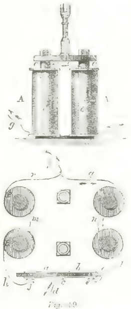

Fig. 899.

no less than 4,764lbs., or more than two tons, to separate the contact.

It may be interesting to give the practical details of one of these electro-motive machines. Without in the slightest degree intending to undervalue the merits of other machines, we select one, the invention of M. Froment, that has excited a good deal of attention in Paris. In this machine four hollow cylinders, two of which are seen at A, B, Fig. 838, are surrounded by a great length of wire, covered with silk, for the purpose of conveying the electric current. Solid cylinders of soft iron C D enter without friction into the hollow cylinders. The cylinders C, Fig. 838, and C C, Fig. 839, are united at their upper part by a transverse piece, also of soft iron: these cylinders are suspended at the extremity E of the beam E F G and the cylinders D are also suspended from the point G. Motion is communicated to the pieces C D, by the action of the electricity, by which means the beam is made to oscillate on the point F in the manner about to be explained. This beam is produced as far as H, where it is hinged to a connecting rod H K, the lower extremity of which is attached to a crank K L. The oscillation of the beam thus produces the rotation of the crank, which is regulated by the fly-wheel.

In order to understand how it is that the electricity gives motion to the pieces C D we must refer to the upper part of Fig. 839, in which are represented the iron cylinders C C inserted within the hollow cylinders A A, about half-way down. Two other iron cylinders C′ C′ occupy the lower half of the hollow cylinders, and are connected together by an iron pin passing below them. Thus we have two distinct horse-shoe arrangements, C C and C′ C′, both placed in such a manner as to become powerfully magnetized when the voltaic current is allowed to circulate round the cylinders A. The two magnets formed in this way have the poles of opposite names opposed to each other, so that they attract each other, and tend to unite; but as the magnet C′ C′ is fixed, the magnet C C is set in motion, thereby pulling down the extremity E of the beam. No sooner is this done than the voltaic current ceases to circulate round the cylinders A, and consequently the bars C C, C′ C′, becoming demagnetized, cease to attract. At the same moment the current is made to pass round the cylinders B; the bars D, becoming magnetic, are attracted down thereby, also lowering the extremity G of the beam. Having produced this effect, the electricity ceases to circulate round B, but passes over to A, and so on alternately.

In order thus to make and break contact in succession, the axis which is made to revolve carries an eccentric L, which gives a reciprocating motion to a slide *a a*. This slide is formed of a small plate of ivory, and is covered in a portion of its length with a metallic strip *b*. A copper wire *c* is bent so as to press constantly with its point upon this metallic strip, notwithstanding the reciprocating motion which it receives from the eccentric L. This wire communicates with one of the poles of the voltaic battery by means of the conducting wire *d*, which enters at *o* into the chest containing the battery. Two other copper wires *e f* also rest with their points on the slide *a a*, and communicate one with the wire *g*, which comes from the cylinders A, the other with the wire *h*, which proceeds from the cylinders B. The reciprocating motion of the slide *a a* brings the plate *b* alternately under the wires *e* and *f*, so that the wire *c* is put in communication at one moment with the wire *g*, and at another with the wire *h*, by means of the metallic plate *b*. All this will be better understood by referring to the lower part of Fig. 839, which is a horizontal section of this portion of the machine. Here we see that the electric current proceeding from one of the poles of the battery along the wire *p* completes its circuit by passing over to the wire *d*, and in doing so it can follow one of two different roads, according to the position of the slide *a a*. In the position shown in the figure the current passes from *p* to *q*; then turns round and ascends the first cylinder A; passes by the wire *n* to the second cylinder A, round which it circulates in descending, and it quits this second cylinder by the wire *g*, and proceeds from *e* to *c* by means of the metallic plate *b*; lastly, the current returns to the battery by the wire *d*. It will be seen in this case that the course of the current round the cylinder B is interrupted, because the portions *f c* of this path now consist of the non-conducting ivory. When, however, by the rotation of the axis the eccentric brings the metallic plate *b* in contact with the wire *f*, the electricity circulates round the cylinders B, and does not pass round the cylinders A.

The most powerful engine of this kind yet made has been equal to one horse. The inventor uses these electro-motive machines to give motion to dividing engines for graduating the limbs of circles for measuring angles. The results are said to be very satisfactory.[1]

In proceeding to notice those forms of apparatus which have been contrived for supplying current electricity without the intervention of a voltaic battery, we must enter into some scientific details which are important to be clearly understood. The voltaic battery is at all times a constant source of trouble and expense, and it would certainly be a great advantage if it could be superseded by a magneto-electric machine.

The intense degree of *magnetism* induced by dynamical electricity (*i. e.* by the *motion* of *electricity*) led naturally to the expectation of a converse action, viz. a disturbance of *electricity* by the *motion* of *magnets*; but for many years all attempts to exhibit this action failed, and many intermediate steps were necessary to pave the way for Faraday's great and long-sought discovery of *magneto-electricity*.

The first of these steps was the discovery of *secondary currents*, or the induction of one voltaic current by another. If wires forming parts of two distinct circuits, and completely insulated from each other, be made to run parallel and very near together for a considerable length, although the steady flow of a current through one wire produces no effect on the other

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(1) Delaunay, Cours Élémentaire de Méchanique. Paris. 1851.

wire, yet if this current be suddenly stopped, a momentary current or *wave* of electricity flows through the second wire in the same direction as the current which has just ceased; and if the original current be suddenly re-established, another such momentary wave is induced, but in the contrary direction. These secondary currents are also induced in the same wire with the inducing current, from which they are distinguishable by several characteristics, but chiefly by their greater intensity or power of forcing a way through imperfect conductors. Hence they give sparks and very intense shocks in cases when the primary current could not penetrate the thinnest layer of air, or affect the most sensitive nerves. Hence also arises the singular effect of passing a feeble current through a *coil, i. e.* a great length of wire, covered with silk or other insulating matter, and then wound on a reel. This imitates, with a single voltaic pair, some of the effects of a multiple battery; not, indeed, producing any augmentation of the continuous effects, such as electrolysis and the heating of wires, but only of those effects which are confined to the moment of breaking the circuit, such as the spark and shock; for at that moment all the turns of the coil react on each other, all tending to induce a current in one direction, which current therefore resembles that set in motion by a very numerous series of very small and weak batteries—it has no greater quantity than if it were induced by a single turn of the coil, but a far greater momentum, or power of overcoming resistances.[1]

The next step was the discovery, that these effects were greatly exalted by the presence of an iron core or electro-magnet within the coil.

Faraday also found that secondary currents might be induced not only by the sudden commencement or stoppage of the primary current, but by the sudden approach to or removal from each other of two wires, in one of which a continuous current is flowing. The approach of the inducing wire induces a current in the contrary direction; its removal, a current in the same direction as its own.

Now putting together all these facts, and bearing in mind that a magnet acts in all respects like a cylinder or bar, in which currents are constantly circulating round the axis in one direction, it will be seen that there are two modes of proceeding, by which we may expect to make it induce momentary currents in a surrounding cylinder or helix; 1. by suddenly demagnetizing or remagnetizing it, or still more forcibly by changing its poles; 2. by suddenly withdrawing it from the helix, or reinserting it. This latter is the easier experiment, and afforded the first instance of an electric current excited by the magnet alone, but then the current was too weak to be recognised by any other than its magnetic effects on a galvanometer, so that, to avoid all appearance of reasoning in a circle, it became very desirable to exhibit this new property of the magnet, not merely as magnetism, but as electricity.

In trying the other experiment (1) the destruction or reversal of polarity was at first accomplished by electricity, thus:—

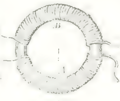

Fig. 840.

On a ring of soft iron, were coiled two lengths of insulated wire, in such a way that each coil occupied its own separate half of the ring, Fig. 840. Now, by sending a voltaic current through one of these coils, as A, the whole ring could be polarized, not so as to exhibit magnetism, but to form a closed magnetic circuit, like that of a horse-shoe magnet with its armature on. By stopping or reversing the current, the polarity of the ring was of course destroyed or reversed. Now, at every such change a momentary current flowed through the other coil B, though neither connected with the battery, nor so situated as to have secondary currents induced in it by the coil A.

The same effects are produced if the ring consists of two halves, and without interrupting the primary current or demagnetizing A, whose magnetism is in this case manifest, we simply detach it from B, or replace it. It only remains then to dispense with the battery, and to polarize and depolarize the iron B by magnetic induction alone. Thus, suppose A with its coil to be removed, and its place supplied by a permanent steel magnet; by alternately removing and replacing it, the soft iron semicircle B will, at each change in its state, induce a momentary current through the surrounding coil; and the same effects will be doubled if we turn the magnet round on the dotted line as an axis, so as to present alternately different poles, and thus constantly reverse those of the soft iron.

These effects are still further exalted by alternately interrupting the circuit of the coil B, precisely at the moments when the iron is depolarized, so as to take advantage of the secondary current. These breaks are easily effected by a little wheel fixed on the same axis as the magnet, or the armature B, for it matters not which is made to revolve, and by nicely timing these motions, the spark, the shock, and all the other effects of electricity are produced, and the contrivance constitutes a *magneto-electric machine*, one form of which (Saxton's) is shown in Fig. 841.

A A is the magnetic battery composed of several thin layers of steel, which being separately magnetized to saturation, give a much greater power than a solid horse-shoe of the same thickness. B B is the middle portion of the armature, whose ends are turned at right angles towards those of the magnet (which they nearly touch), and are covered with two coils containing together from 50 to 800 yards of insulated wire. One end of this wire communicates with the axle *d d* on which the armature is fixed, and which is rapidly turned by the band passing over the wheel E. The other end of the wire is connected with the hollow cylinder *f* which surrounds the axle, but is insulated from it. A spring *g* constantly presses against this cylinder, and communicates with the plate *h*, which is one of the electric poles of the machine. The other pole, *k*, (insulated from *h*,) communicates by the pillar *l* and spring *m* with the little wheel *d*, called the *break*, the circumference of which is partly of metal and partly of wood or ivory,[1] so as to interrupt and renew, twice in each revolution, the metallic connexion between *m* and the axle. At every such interruption, (which occurs when the armature has just left the poles of the magnet,) a brilliant spark appears, provided the circuit be completed by joining *h* and *k*. This connexion may be made through the human body, or any apparatus by which the other effects of the current may be shown. These effects perfectly resemble those of the secondary voltaic current, and like them, seem to hold an intermediate place between those of tensional and of current electricity. Hence this machine is peculiarly instructive as supplying a link, which might otherwise seem wanting, between the common electrical machine and the voltaic battery, for it exhibits the chief properties of *both*, though in a degree far inferior to either.[2] This will be understood by remembering that in tensional electricity the statical effects, or those of the *charge*, are continuous, and the dynamical, or those of the *discharge*, last only for an instant; while in voltaic batteries, on the contrary, the latter are continuous, and the former, if observable at all, are only momentary, viz. at the moment of breaking the circuit. But in the magnetic machine both the charge and discharge are only momentary, or of too short duration to be sensible, were it not for their rapid repetition. By turning the machine rapidly, wires may be kept at a red-heat, because they have not time to cool between the successive discharges.[3] As the current is *reciprocating*, it follows of course that in decomposing water by it, the gases are not separated, but a mixture of both is obtained from each pole alike. Hence, when the elements of an electrolyte are required separately, another form of break is employed by which every alternate spark is omitted, and the available power of the machine is reduced one-half. Yet such machines are found to furnish on a large scale a cheap supply of electricity for electro-plating and gilding, and their use for these purposes has been patented.[4] By combining several machines having all their armatures and breaks fixed on the same axis, but in different positions, an almost continuous current is kept up.

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(1) Of all forms of electricity, these secondary currents are the most remarkable for their physiological effects. By rapidly breaking and renewing the primary current by a toothed wheel, against which a spring presses, a rapid succession of shocks is produced, which, when received through metallic handles, cause an involuntary muscular contraction, rendering it impossible to relinquish the grasp. When received from water, they are more endurable, though even in that case we have seen a strong man trying in vain to pick up coins placed only two or three inches below the surface.

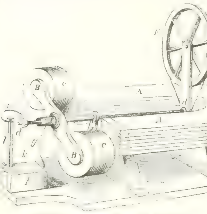

FIG. 341. MAGNETO-ELECTRIC MACHINE.

It will be observed that the effects of this machine are, strictly speaking, not due so much to the current induced directly by the magnet, as to the *secondary* current derived therefrom. But by other arrangements the *primary* magneto-current may be made sensible as a continuous current of extremely low tension. In fact, it has been established by Faraday that in general neither a magnet, nor any conducting body within its influence, can be moved without generating currents in one or both of them, provided a channel be open for their circulation; but they can only be detected by the galvanoscope. Their directions are always *across* the line of motion, and can be determined on the principles already explained. The magnet may be regarded as a natural machine which by some unknown mechanism converts *mechanical* into *electrical* motion, and *vice versâ*, and this in the peculiar way that a screw converts one mechanical motion into another, viz. rotation on an axis into progressive motion along that axis, and *vice versâ*. Thus we have seen that the insertion of a magnet into, or its withdrawal from, a helix or other cylinder generates currents round that cylinder;—*longitudinal* motion thus producing *rotatory* currents; and the converse of this is true; for the *rotation* of a magnet on its axis, or of other conductors round it, induces both in magnet and conductors *longitudinal* currents, which, if a conductor be supplied for their return, flow from the centre of the magnet to its ends, or else from its ends to its centre, according as the rotation is to the right or to the left. This is simply the reverse of that electro-magnetic experiment in which a metal cap or wire cage, poised on the top of an upright magnet, is made to revolve by a voltaic current passing up or down it. Instead of producing the rotation by a current, we may produce a current by the rotation; but this current will be in the contrary direction to that which would produce the same rotation. So also, all the common electro-magnetic experiments may be reversed and become magneto-electric ones, by substituting a galvanoscope for the battery, and then making the movable parts rotate by external force. Thus Saxton's machine may be regarded in this light as an inversion of Ritchie's revolving magnet,[1] Fig. 812, and the first magneto-electric currents detected by Faraday were those flowing along the radii of a copper disk revolving between the poles of a horse-shoe magnet, being an exact inversion of the revolving star experiment.

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[1] The [illegible] is [illegible] but this is [illegible] as [illegible] of the [illegible].

[2] The [illegible] to produce [illegible] statical attraction and repulsion. [illegible] the gold-leaf electro[illegible] has been [illegible]. [illegible] however [illegible] but [illegible] and [illegible] they [illegible] only the [illegible].

[3] The *quantity* of electricity passing in each discharge is proportional to the [illegible] of the wire forming the coils, but its *intensity* [illegible] proportional to the *length* of wire. Hence it is usual to employ for different purposes two distinct armatures, on one of which is coiled a *great length* of very *fine* wire, and on the other [illegible] of [illegible] *shorter* wire. The former is used when the current has to penetrate bad conductors, as in giving shocks, but the latter when quantity is required, as for heating wires, or for showing the fusion and combustion of a metal point fixed on the end of the spring *m*.

[4] Ohm's theory teaches us that in using this machine for electrolysis, there must be for every different electrolyte a certain definite *length* of wire which will produce the greatest effect obtainable with a given *weight* of wire. Consequently, whatever may be the size of the wire, it should always have this *length*, which will depend on the conducting power of the electrolyte. For plating and gilding, a length of about 100 yards is employed, and in Woolrich's great machine the wire is [illegible]th of an inch thick. This affords a current equivalent to the separation of about 2 oz. of silver per hour, which is equal to [illegible] grains of water decomposed, or 800 cubic inches of gas produced. But for decomposing water on account of its low conducting power, the proper length of wire would be greater.

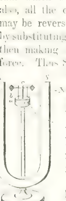

Fig. 812

In all these cases the current induced by any motion is always such as would tend to produce the contrary motion.[2] Hence it is evident that every motion tending to induce magneto-electricity, must encounter a certain mechanical resistance apart from the common resistances of friction, air, &c., and proportional to the quantity of electricity disturbed. In Saxton's machine this resistance is at once referred to the mere attraction of the magnet for the armature; but in fact all magnetic attraction is only a particular form of this resistance. It often assumes other forms, some of which were observed by Arago before the discovery of magneto-electricity. He found that oscillating magnets were brought to rest sooner in the neighbourhood of masses of copper or other electrical conductors, than in their absence; and that if both the magnet and the copper were free to move, any motion of either of them dragged the other after it, though all effect of the air was excluded by interposing plates of glass. Magnets and copper discs of many pounds weight were made to revolve in this way; and a small piece of copper suspended by a thread between the poles of Faraday's great electro-magnet, and spinning rapidly by the untwisting of the thread, is *instantly arrested* in a striking manner, the moment that a mass of iron is polarized. These effects are common to all good electrical conductors, however destitute they may be of magnetism properly so called, *i.e.* of action on the magnet when *at rest*.

Even in the common galvanometer every mechanical displacement of the needle induces a current round the coils. Whenever its north pole is moving *eastward*, a current flows in such a direction as would tend to deflect it *westward*, and *vice versâ*. Hence the reaction of these currents on the needle tends to bring it to rest, or to retard all its motions, and thus a galvanometric coil, or still better, a solid mass of copper of the same form, surrounding the needle, as in Fig. 813, tends to check or steady its vibrations, and is used for this purpose in magnetic observatories. An excellent form of compass has been contrived by Sir W. Snow Harris on this principle.

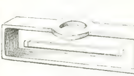

Fig. 813

Even the currents induced by the earth's magnetism may be rendered sensible thus. If a helix, the ends of which are connected with a galvanoscope, be placed with its axis in the position of the dipping needle, the sudden insertion or removal of a core of common iron will cause momentary currents to circulate through the helix, because the iron becomes a magnet the moment it is placed in this position. The same effects will ensue if without removing the core, which should be of very soft iron, we turn both it and the helix (which must be connected with the galvanoscope by *flexible* wires) end for end, for by this action the poles of the soft iron are reversed. Here, however, the earth only acts mediately through the iron, and is not shown to induce electricity, but only magnetism; but the last experiment will succeed, although in an inferior degree, with an empty helix, thus proving the direct action of the earth in inducing currents, just like any other magnet.

Again, if a disc of copper be made to revolve horizontally over a magnetic pole, currents will tend to flow either from the centre of the disc to its edges or

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(1) This is the general form of this instructive apparatus. N S are the two poles of a horse-shoe magnet; *a b*, a wooden cup for mercury, divided into two parts, *a* and *b*; *a* is connected by a wire with one end of a small single-cell galvanic battery, and *b* with the other end. *c* is the electro-magnet, consisting of a small bar of soft iron, surrounded at its ends with a continuous coil of stout copper wire, the two terminations of the wire dipping into the mercury. The polarity of either end will vary according to the termination of the wire which may be in *b* or *a*. The electro-magnet is supported on a central vertical axis, which passes through a collar, and terminates in a point resting in a small agate cup so that the electro-magnet is free to move in a horizontal plane. Now when the electro-magnet is placed at right angles to the line joining N and S, and the current gives one end, say X, a north polarity, the end X will be repelled by N and attracted by S; but the momentum acquired by the motion will carry it a little beyond the line of neutrality, and thus the wire dipping into the mercury *b* will pass over the partition into the mercury *a*; X will now be a south pole, and consequently will be repelled by S and attracted by N; but as soon as it gets to N, its momentum swings it over the partition into *b*, in which case it is repelled by N and attracted by S. The poles of the electro-magnet being thus reversed the moment the wire passes from one division of the mercury cup into the other, a series of alternate attractions and repulsions between the poles of the electro-magnet and those of the magnet N S takes place, and thus the former, being free to move, rotates with great rapidity.

(2) This is a general rule applicable to the action between currents and currents, as well as between currents and magnets. For instance, two parallel currents flowing in the same direction attract each other; but the mutual approach of two parallel wires, only one of which is conducting a current, tends to induce a contrary current in the other wire. Again, two parallel and contrary currents repel each other; but the separation of two wires, only one of which conveys a current, will induce a current in the other wire in the same direction. Everywhere we meet with the same principle of action and reaction.

vice versâ, according as the rotation is to the right or left, because it may be regarded as forming part of the top of one of the revolving caps so well known in electro-magnetic experiments. To detect these currents, one wire of the galvanoscope is connected with the axle of the disc, or bearings, and the other with a spring that touches its edge. Now, when no magnet is brought near, the rotation still causes a current to pass, in the same direction as if there were a south pole presented below the disc; the fact being that there is such a pole, viz. the earth's north pole, which, we must remember, possesses the same properties as the south pole of a magnet. As this pole, however, is not directly under the disc, the latter should not, to produce the maximum effect, be quite horizontal, but dipping about 20° towards the south, so as to have its axis parallel with the dipping needle.

On these principles *Electro-telluric* machines have been constructed, for producing without magnets most of the effects of Saxton's machine, but in a lower degree. [See APPENDIX.]

ELEMI. A concrete resinous exudation, of which there are several varieties. The Gum Elemi of commerce is said to be furnished by *Amyris hexandra* of the West Indies. It is also said to be furnished by the *Canarium balsamiferum* of Ceylon, and by the *Icica icicariba* of the Brazils. It is imported in cylindrical cakes, covered with palm leaves; but, as it is scarce and costly, it is sometimes adulterated with common fir-tree resin. Its chief use is to form pastilles, or to burn as incense: it has been recommended as an ingredient in ointments, and also in some kinds of varnish. Fresh elemi is soft and viscid, but becomes hard and brittle by cold and by age; it is yellow, translucent, and of a peculiar odour, somewhat resembling fennel: it yields a volatile oil when distilled with water. It contains about 60 parts of an acid resin, soluble in cold alcohol, and 20 parts per cent. of an indifferent crystallizable resin soluble in hot alcohol. The composition of the former is $C_{10} H_{32} O_4$, of the latter $C_{40} H_{33} O$.

ELIQUATION. An old method of reducing ores of silver, now seldom resorted to. It consisted in fusing alloys of copper and silver with lead: this triple alloy was cast into round masses, which were set in a furnace upon an inclined plane of iron, with a small channel grooved out, and heated red hot: the lead melted out, and by its attraction for silver, carried that metal with it, and left the copper in a reddish-black spongy mass. See SILVER—ASSAYING.

EMBANKMENT. See DRAINAGE — DYKE — RAILWAY.

EMBOSSING. The art of producing raised figures or patterns upon textile fabrics, paper, leather, &c., has already been brought under the reader's notice in the articles CALENDERING and BOOKBINDING. In the present article we propose to point out a few general applications of the art.

In the year 1824, the Society of Arts, London, rewarded Mr. J. Straker for a method of producing embossed designs on wood. Raised figures on wood, such as are employed in picture frames and other articles of ornamental cabinet work, are usually produced by carving, or by casting the pattern in plaster of Paris or other composition, and cementing or otherwise fixing it on the surface of the wood. The former method is expensive, and the latter not always applicable. Mr. Straker's invention, which may be used either by itself or in aid of carving, depends on the fact, that if a depression be made by a blunt instrument on the surface of wood, such depressed part will again rise to its original level by subsequent immersion in water. The wood to be ornamented having first been worked out to its proposed shape, is in a state to receive the drawing of the pattern; this being put in, a blunt steel tool, a burnisher, or a die is to be applied successively to all those parts of the pattern intended to be in relief, and at the same time is to be driven very cautiously, without breaking the grain of the wood, till the depth of the depression is equal to the subsequent prominence of the figures. The ground is then to be reduced by planing or filing to the level of the depressed part; after which, the piece of wood being placed in water, hot or cold, the parts previously depressed will rise to their former height, and will thus form an embossed pattern, which may be finished by the usual operations of carving.[1]

In 1842 Mr. Baggaly patented certain improvements in making metallic dies and plates for embossing. The dies commonly used are produced by welding steel to the body of a wrought-iron block, and afterwards cutting or stamping the subject thereon. By the new method, the subject of the plate or die is produced from flat plates of steel, then cast in molten metal, and, lastly, soldered to cast-iron blocks. A model of the subject required to be sunk in the die being provided, a mould is made therefrom in plaster, sulphur, or other suitable material, and of nearly the same thickness in every part, the general figure of the back of the mould nearly corresponding to that of the face. From the back of this mould a cast-iron die or block is obtained in the usual way by means of a plaster model, of sufficient substance to bear the operation of stamping. From the face of the mould a model is obtained for casting a sinker containing the raised part of the subject in iron. This sinker must have a stud at its back for attaching it to the press or stamp hammer. The die-block and sinker having been adjusted in the press or stamp, a plate of steel or other suitable metal is heated to redness, and placed upon the face or upper surface of the cast-metal die-block; the sinker is then struck down upon the plate of steel, which, after several blows and repeated beatings, is brought into the form of the die-block on the under side, and of the sinker on the upper side. The steel plate is then trimmed, and hardened if required. It is then cleaned at the back and edges, and tinned over those parts. The face of the die-block is also cleaned and tinned, and the plate is then fixed by soft solder in the die-block, and pressed

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(1) Transactions of the Society of Arts, vol. xlii.

whilst hot, so as to bring it firmly to its proper seat or bed. After this fixing it is "[illegible]," or worked upon by the tool, when it is ready for use.

Instead of sinking the figure of the dies out of flat plates, the figures may be produced in the face of the matrix or die by casting them from molten steel. Or, instead of steel, castings of malleable iron or brass and other alloys may be substituted.

Mr. Schroth has a patent for producing raised figures, or fac-simile copies of designs or patterns in leather or other similar material, such copies to be applied to all the purposes for which basso-relievo ornamental work is employed, such as the decoration of buildings and apartments, as medallions, cornices, panels, rosettes, picture frames, &c., and for cabinet work and other articles of furniture. The blocks or moulds, which are made of type metal and of fusible metal, are prepared from clay or plaster models of the objects to be copied; the leather is then forced into all the counter-sunk interstices of the mould in the following manner:—the skin is first beaten in water until it becomes properly softened and thickened; the operator then takes it out of the water, and rolls and works it with his hands, so as to make it shrink, that is, to increase its thickness at the expense of its width and length, after the manner of fulling. He then places it in the middle of the metal mould, and having ascertained the centre part of the design, he proceeds by gently unrolling the edges of the skin, and with the ends of his fingers presses it into the interstices of the die, stretching out the leather, and proceeding gradually from the centre to the edges. When the principal cavities are filled, the leather is pressed into the smaller ones by means of a wooden, bone, or copper tool, similar to that used in modelling, making use also of a brush, with which the skin is gently struck. A sponge is also pressed down for the purpose of absorbing the water. When properly filled in, the leather may be dried and finished by heat; the mould containing the skin is to be placed on a chafing-dish until the temperature of about 108° to 144° Fahr. is attained. During the drying, papier-maché or other suitable material is forced into the deepest cavities of the skin, to prevent it from receding from the die; the preparing tool and sponge must also be used repeatedly for the same purpose. The elasticity of the leather and its contraction in drying, will allow it to be drawn out of the deep and counter-sunk parts of the mould.

A second method of compressing and drying is by employing an absorbent substance in powder, such as well-dried sawdust, in which case the mould, with the skin forced into it, is placed in the bed of a press, and enclosed in a frame of wood or metal, formed of side pieces, without top or bottom; the top edges of the frame being about two or three inches higher than the mould when the design is not much in relief, and from about six to twelve inches or more when the embossing is raised to a greater degree. This frame being filled with sawdust, a plate, or follower, is placed above the frame, of such a size as to enter it freely. The screw of the press being turned, the compression of the sawdust forces the leather into all the cavities of the mould. After some time the mould may be taken out, and dried by heat, or in the open air, according to circumstances. The cavities in the back of these embossed figures may be filled up with paper, sawdust, pulverized cork, mixed with glue or hot resin. The face may be painted, gilt, or silvered, if previously rendered impervious by gum-lac or any suitable resinous substance.[1]

EMBOSSING-PRESS. Figs. 844 and 845 represent two views of a highly ingenious and beautiful machine, designed and constructed by Mr. Edwin Hill, for the purpose of impressing the medallion stamp upon the postage envelopes. Several of these presses have been in use at Somerset House during the last eleven years.

Other machines, invented by Sir William Congreve for stamping tickets relative to the post-horse duties, were, on the introduction of the post-office envelopes, used for embossing these medallion heads, for which purpose they were modified by Mr. Hill. In these machines the blow was given by a falling weight; but the construction did not admit of a high quality of embossing; and there were other objections to the Congreve machines: Mr. Hill, therefore, invented a new press, by which greater precision, finish, and rapidity of execution were attained by the introduction of the principle of the fly and screw press. The difficulties to be overcome were: 1. To accomplish the whole operation of embossing and printing the coloured ground entirely by the machine, the ordinary plan being to ink the die by hand; and, 2. To perform the operation with such rapidity as to keep down the expense to an exceedingly low scale; for, the postage stamps being used mostly in the collection of so low a duty as one penny to each stamp, it is obvious that any sensible cost of production would absorb an important fraction of the postage revenue.

The machine consists of a strong fly and screw press, with an inking apparatus, including a peculiar contrivance for accelerating the rate of stamping, without accelerating the angular motion of the fly and screw. The envelope is placed under the stamp by an attendant at the precise moment when the stamp is being inked; the position of the envelope being determined by guides, so that the impression may be in the same place in all the envelopes. When the die descends and makes the impression, it immediately rises again preparatory to another blow: a second attendant removes the stamped envelope, and the first attendant puts a blank envelope in its place. So rapidly are these motions performed, that a blank envelope is placed under the die, stamped, and removed, sixty times a minute; and so dexterous do the two attendant boys become, that, while feeding the press, they are also engaged in reading out of an open book placed in a convenient position before them.

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[1] Newton's London Journal of Arts and Sciences, [illegible] vol. xxix. 18[illegible]. The [illegible]

We will now describe the working parts of the press. The main spindle is driven by a strap, at the rate of one turn of the machine per second; each turn producing an embossed medallion stamp. From the main spindle, motion is communicated *first* to the fly and screw, which of course rise and fall alternately, and *secondly*, to the bolt of the press, at the lower end of which the die is attached. In the *third* place, motion is communicated to a very strong steel punch or drift, which, at the moment when the blow is given, is interposed between the end of the descending screw and the head of the bolt, thus transmitting the force from the screw to the bolt. When the impression is completed, this punch is withdrawn, and the bolt ascends in order that the die may receive its supply of ink. *Fourthly*, motion is given to the inking apparatus, which consists of a ductor, an inverted inking-table, and a sliding frame, carrying the four composition rollers. The machine, when in motion, can be stopped by means of an apparatus so constructed that when pressed down, the principal cam, upon arriving at a certain point of its revolution, is at once arrested. It is necessary to stop the machine in one particular position, so as to allow the dies and the inking apparatus to be readily got at.

The different members of the machine are shown in Figs. 844 and 845, the views of the same parts being indicated by the same letters in both engravings. A A is the main spindle, and S the driving-strap; *c* and [illegible] two cranks, one at each end of the main spindle, which, by means of the two straps *d* and *d′*, passing over the pulleys *e* and *e′*, and attached to the drum *f*, which is fixed upon the screw *g*, turn the screw, together with its fly *g′*, backwards and forwards alternately, producing thereby its alternate rise and fall. These two cranks, however, are not made fast upon the main spindle, but are operated upon, each at its proper time, by two other cranks *h* and *h′*, fixed to the main spindle. This provision of loose and fast cranks is rendered necessary by the rebound of the screw and fly from the blow, which outruns the cranks, and would break the straps but for this precaution. Upon the main spindle is a cam [illegible], which moves the lever *k* backwards and forwards, and, through the horizontal bar *l*, the punch *m* is also moved backwards and forwards, and thus interposed between the screw *g*, as it descends, and the bolt *b*, at the moment when the blow is given: [illegible] is a second cam upon the main spindle A A, which, by alternately raising and depressing the levers [illegible] raises and depresses the bolt *b*, to the lower end of which the die is attached. *r* and *r′* are toothed wheels, for driving the inking apparatus; *r′* has a crank pin, which, by means of the link *z*, sways backwards and forwards the arm *t*, and through that the arm *t′*, fixed upon the same spindle. This last arm *t′*, through the link *z*, draws backwards and forwards the inking-frame

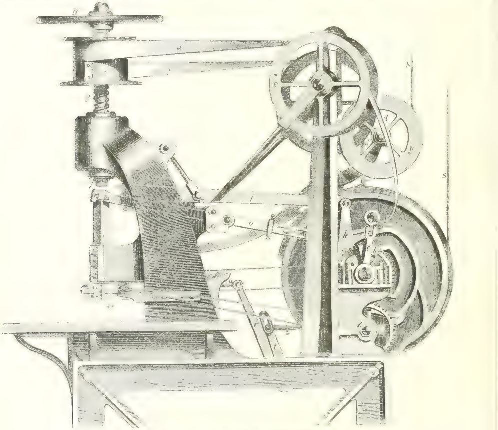

Fig. 844.—ELEVATION OF EMBOSSING-PRESS.

v, with its four composition rollers, which ink the die by running under it when the bolt is in its raised position, as shown in the figure. *w* is the inverted ink-distributing table: it is circular, and is acted upon by a slack band, which turns it round feebly whenever the inking-rollers lose contact with it. *x* is the doctor, furnished with a roller which is constantly turned round by a band: *y* is a slacking pulley fixed to the arm *y'*, on which arm is also a brake, which binds against the main driving-wheel, and a strong tooth, catching a projection on that wheel, and bringing the machine to a dead stop always in the same position, *i.e.* nearly in the position shown in Fig. 844.

Similar machines have lately been constructed for the use of the Prussian and Neapolitan governments, and for the East India Company. These presses are also used in the manufacture of embossed wafers.

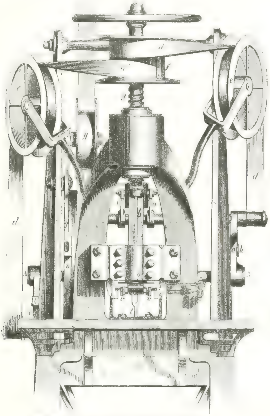

Fig. 845. END ELEVATION OF EMBOSSING-PRESS.

EMBROIDERY is an ancient art, as we find from the mention made of it both by sacred and profane writers. From a very early period, people knew how to embroider stuffs and vary their colours, either by means of the needle, working into a plain ground threads of different colours, gold, or precious stones, or by introducing such threads into the tissue of the stuff while preparing the warp. The directions for making the Tabernacle and its embroidered curtain show the knowledge of this art communicated to the Hebrews. (Exod xxvi. 1—31; xxxix. 2, 3, 5, 8, &c.)

The Medes and Babylonians of ancient times were celebrated for the beauty of the draperies of their apartments. The hangings which decorated their palaces were wrought by the needle, which in eastern nations is still employed in embroidered works. Chardin says of the Persians,—"Their tailors certainly excel ours in their sewing. They make carpets, cushions, veils for doors, and other pieces of furniture of felt, in Mosaic work, which represent just what they please. This is done so neatly, that a man might suppose the figures were painted instead of being a kind of inlaid work. Look as close as you will the joining cannot be seen." Tents, which are so much used in hot countries among Nomadic tribes or on military excursions, have for ages kept the skill of the eastern embroiderer in practice. The covering of tents among the Arabs is usually black goat's-hair, so compactly woven as to be impervious to rain. In addition to this, there is usually an inner tent of white woollen stuff, on which flowers are embroidered. Curious hangings are also hung over the entrances. A tent of a late king of Persia, which is said to have cost 2,000,000*l.*, and to have been a load for forty camels, "was embroidered with burnished gold, studded with precious stones and diamonds, interspersed with rubies and emeralds set with rows of pearls; and there was painted thereon a specimen of every created thing, birds, and trees, and towns, cities, seas, and continents, beasts and reptiles."

This art was also generally known among other Asiatic nations. Homer speaks of embroidery as the occupation of Helen and of Andromache; he mentions also the golden cincture of Calypso, and that of Circe. At that period, (unless the poet's imagination has rendered his description too partial,) embroidery approached painting in the truthfulness of its imitations: in Ovid's fable of Minerva and Arachne, the art is praised as giving the touches of light with a degree of fidelity beyond that of painting, but which they were enabled successfully to accomplish in wool. Many modern authors are, indeed, disposed to seek the origin of painting among the Greeks in the talent of the Ionian women in tapestry-work. We find even, in the Memoirs of the Academy of Sciences, an interesting dissertation on Painting, in which the author, describing the numerous varieties of that art, makes mention among them of tapestry worked with the needle or at the loom, and of designs executed on white silk and cotton cloth, by employing various dyes which penetrate the stuff.

At the present day the most patient and laborious embroiderers are said to be the Chinese; their regularity and neatness are very great, and the extreme care with which they work preserves their shades bright and shining. The Indians also excel in this kind of work. "They embroider with cotton on muslin, but they employ on gauze, rushes, skins of insects, nails and claws of animals, walnuts and dry fruits, and, above all, the feathers of birds. They mingle their colours without harmony as without taste; it is only a species of wild mosaic, which announces no plan and represents no object. The women of the wandering tribes of Persia weave those rich carpets, which are called Turkey carpets from the place of their immediate importation. But this country was formerly celebrated for magnificent embroideries, and also for tapestries, composed of silk and wool, embellished with gold. This rather beautiful art, though not entirely lost, is nearly so, for want of encouragement. But of all Eastern nations the Moguls were the most celebrated for their splendid embroideries; walls, couches, and even floors, were covered with silk or cotton fabrics, richly worked with gold, and often, as in ancient times, with gems inwrought."[1]

The poet Cowper has immortalized Mrs. Montague's feather hangings. Various articles of dress have of late years been covered or ornamented with feathers, such as muffs, tippets, &c. In Canada, the women embroider with their own hair and that of animals, copying the ramifications of moss agates and of plants; they also insinuate into their works skins of serpents and morsels of fur, patiently smoothed. The Negresses of Senegal embroider various skins of animals with flowers and figures of all colours. The Turks and Georgians embroider the lightest gauze or crape; they use a very delicate gold thread, and represent very minute objects on morocco without varying the form or fraying the gold. They have a habit of ornamenting their embroidery with pieces of money of different nations, and travellers often find in their old garments valuable and interesting coins.

In Saxony, embroidery is practised on muslin with untwisted thread, and is very beautiful. That of Venice and Milan is celebrated, but costly. France has also a reputation for embroidery; but the Germans, especially those of Vienna, are said to be most successful in the art. In England, as Mrs. Stone remarks, the practice of ornamental needlework and of embroidery have gradually declined from the days of Elizabeth. "The literary and scholastic pursuits which in her day had suspended the use of the needle did not, indeed, continue the fashion of later times; still the needle was not resumed, nor perhaps has embroidery and tapestry ever, from the days of Elizabeth, been so much practised as it is now."

Embroidery at the present day is not merely a female occupation, but a considerable branch of industry, which occupies thousands of young persons and children, and makes large demands not only on the manual dexterity, but on the intelligence of those who practise it; for the work of the embroiderer requires that he should understand the nature of the materials with which he deals, their several aptitudes to take certain dyes, and to bear certain processes. It requires also a knowledge of drawing, and of the proper arrangement of colours, with inventive power to produce novelties, and methods of executing them in a tasteful and economical manner.

The practice of tapestry-weaving with a shuttle was originally done in a standing posture; the threads of wool being stretched perpendicularly, and not, as they are now, wound upon a beam. The warp was confined by a piece of wood, to which heavy weights were attached. The Egyptians were the first, according to Pliny, who changed the old and inconvenient method, and introduced the custom of sitting to the work, as is now done by the workmen in the royal manufacture of the Gobelins, of Beauvais, Aubusson, &c. The same author informs us that when embroidered materials were old and worn, the ancients were accustomed to transfer the worked parts to a new ground, and thus to give them a prolonged existence. Thus the embroidery was cut out, following the contours of the original design, and then applied, laid on, and sewed upon a plain ground of a different colour. This was a common practice in trimming the robes of Roman matrons, and is what is meant by Ovid and Horace when they speak of such robes being embroidered or bordered with a fringe of purple, &c. The sort of trimming among the Romans, frequently expressed the dignity, sex, and age of the wearer.

The practice of embroidery varies with the nature of the materials worked with. In embroidering stuffs the work is performed in a stretching-frame. Muslin is starched, and then spread out upon a pattern; while working the flowers, it is necessary to count the threads of the muslin both in the warp and in the weft. This makes the work tedious, but it is richer in points, and susceptible of greater variety, than when done at the stretching-frame. Cloths too much milled are not well adapted to this kind of ornament.

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[1] The Art of Needle-Work from the Earliest Ages, by Elizabeth Stone. Edited by the Right Honourable the Countess of Wilton. [illegible] Colburn. [illegible]

In the practice of embroidery, the French divide the art into various classes. The first class is called *white* embroidery, because it is executed on all kinds of white materials, with white cotton, flat, milled or twisted; with braid, edging, &c. This species of embroidery also comprehends—*festoon* embroidery, or that which consists of embroidering and cutting out the edge of the material to a certain pattern traced on paper or on the stuff itself. Festoon embroidery is also employed in the body of the work without cutting out. *Chain-stitch* embroidery, or that which traces the veins and general shape of the pattern in chain-stitch, and fills up the middle afterwards in a similar manner. *Needle-work* embroidery, or simple horizontal stitches, each embracing as much of the material behind as before the thread, and applicable only to thin and soft materials, as muslin, cambric, &c. *Lace* embroidery on tulle, blonde, gauze, &c., manufactured by the aid of the Jacquard loom.

Proceeding from these works in a white material to the embroidery in colours, there are again many kinds. In one of these the figures are raised and rounded, by cotton or velvet, which is placed underneath to sustain them; in another, edging or lace is laid upon the design, and sewn on with thread of the same colour in various stitches; in another, the whole pattern is cut out in velvet or silk, and carefully sewn upon the material with thread or silk. Embroidery *en guipure* is a rich mixture of several kinds of embroidery, and may be executed in gold, silver, feathers, pearls, precious stones, &c. Embroidery in *flat tints* is when the threads and other coloured materials are simply put in juxtaposition; *shaded* embroidery is when the embroiderer seeks to follow nature closely, or to represent in its more delicate shadings the object, natural or artificial, which is to be imitated. Other names of embroidery are derived from the implements employed, as *crochet*, *loom*, or *tambour* embroidery. Under the name of embroidery are also comprehended the numerous kinds of work which consist in forming flowers upon all kinds of tissues, with ribbons or with coloured gauze.

The number of stitches in embroidery is strictly only two; the first embracing the material equally in height and width, and on both sides; the second executed either with a crochet or a common needle, and forming a continuous chain. Embroidery on canvas is distinguished from works in velvet, and from the different stitches for marking linen, and for making fancy articles with beads, &c. Embroidery on canvas is often called *tapestry-work*. The stitches, combined and arranged in various manners, represent the desired figures, and take different names according to the countries where these combinations were first invented. Thus, there is *Berlin-stitch*, *French*, *Hungarian*, *English-stitch*, *Gobelins-stitch*, and many others.

Embroidery, as practised in England, comprehends: 1. Embroidery *on the stamp*, where the figures are raised, and rounded by means of cotton or parchment beneath. 2. *Low* embroidery, where the gold and silver lie low upon the sketch, and are stitched with silk of the same colour. 3. *Gumped* embroidery, which is performed either in gold or silver. A sketch is first made upon the cloth, then put on cut vellum, and afterwards sewed on the gold and silver with silk thread; and on this kind of embroidery are often added gold and silver cord, tinsel, and spangles. 4. Embroidery on both sides of the stuff. 5. *Plain* embroidery, which is flat and even, without cords, spangles, or other ornaments.

The elements of tapestry-work are five; namely, the *design* which the embroiderer is to imitate; the dyed *threads* of wool or silk, variously and properly sorted; the *canvas*, more or less regular, of which the interlacing threads guide the stitch; the *frame* on which the canvas is conveniently stretched; the *needle*, with a large head and a blunt point, which serves to pass the coloured thread freely through the squares or meshes of the canvas. A correct drawing of the object to be reproduced upon the canvas must be constantly under the eye of the embroiderer. Some of these designs are engraved, painted, and coloured upon paper representing canvas, so that the forms and colours exactly fill the corresponding squares to those on which the stitches are to be set. Others are traced upon the canvas itself in outline, or without coloured shadows: in this last case, the embroiderer works according to her taste, and according to the nature of the objects, in arranging the coloured threads, and in putting in the lights and shadows. Tapestry itself, bought ready-made, very often serves for a model, which is imitated on the corresponding part of the canvas, by counting successively with a pin the stitches in such and such a shade of the model, and the squares of the canvas which must receive them; but this, of course, takes more time than working from a design traced on the canvas.

There is also an invention for taking patterns from lithographic drawings, which serves the purpose of embroiderers, especially of such as would imitate the famous Gobelins tapestry. A sheet of thin paper-canvas, or paper on which the meshes of canvas are accurately represented, is applied to a lithographic drawing, and secured to it with soft wax. The design is then copied through the transparent paper-canvas, of which the number of squares, previously reckoned so as to determine the dimensions of the design, shall determine the number of stitches, and the colours which must be employed.

Several kinds of embroidering frame are in use, but one of the most easy to manage is made with a system of iron hooks fixed upon the cross pieces of the frame, and serving to stretch the canvas on the two opposite sides. This sort of frame is now but little used, on account of the price of its construction. The working embroiderers prefer the screw or the lath frames, which are sold at a cheaper rate, and admit of more easy adjustment. But in the lath-frame the material is often stretched too much or too little, and thus is inferior to the screw-frame, in which the stuff can be stretched little or much, according to the wish of the worker. Most of the frames in use have the disadvantage of obliging the embroiderer to sew the two sides of the canvas upon the galloon nailed upon the two rollers, then to roll up the canvas, and fix it to the sides by means of packthread, which is liable to distend it too much, and tear it. Improved frames have been introduced, in which the canvas is secured by blunt points attached to the sides, and covered with a wooden bar, cut half-round, and having along its length a slit or groove of a width corresponding with the points. The sides of the frame are secured and the canvas properly stretched by means of screws. One of these improved frames is shown in Fig. 846.

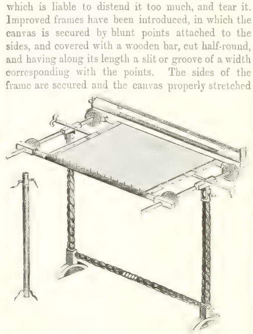


FIG. 846. HAND EMBROIDERING FRAME.

EMBROIDERING MACHINE. As most mechanical processes which have hitherto been performed by hand, can be much better accomplished by a machine, so the refined art of the embroiderer has yielded to the skill of the engineer. In the French Industrial Exposition of 1834, M. Heilmann of Mulhousen exhibited an embroidering machine which enables a female to embroider a design with 80 or 140 needles as accurately, and nearly as expeditiously, as she formerly could with one.

The principle of this ingenious machine is as follows:—the piece of cloth to be embroidered is suspended in a vertical position. The needles with which the ornamental work is performed are not like ordinary needles, with an eye at one end and a point at the other, but are furnished with a point at each end, and the eye in the middle, as shown at V′, Fig. 849; these needles are held by pincers in a frame, and the piece of cloth which is to be embroidered being suspended in a vertical position, the carriage containing the needles is wheeled up to it; all the needles pierce it, and on passing through a certain distance, are seized on the other side by the pincers of a second frame. On drawing this frame away from the fabric, it is evident that the needles must be completely drawn through, together with the threads inserted in them; and on sending the second frame up to the cloth, the needles will be passed through in an opposite direction, and be clipped and drawn through by the first frame. During these motions of the two frames backwards and forwards, the frame in which the cloth is suspended is moved by an attendant in a regulated order, by means of a lever attached to a pantograph; so that, as the attendant goes regularly over the points of a pattern, drawn on a large scale at the side, the cloth is slightly shifted at each motion, and the pattern is repeated thereon, on a small scale, by the passage of the needles.

This machine may be described under four heads. 1. The structure of the frame. 2. The arrangement of the web. 3. The arrangement of the carriages. 4. The construction of the pincers. A front view of this machine is shown in a separate steel engraving.

1. The frame is composed of cast-iron, and is massive. The length of the machine depends upon the number of pincers to be worked. The machine at the French Exposition had 130 needles, and consequently 260 pincers arranged in two rows, an upper and a lower row; its length was 2½ metres, or about 8 feet 4 inches. The breadth of the frame must not be less than about 40 inches. It is usually the same in all machines, and determines the length of thread to be put into the needles.

2. The piece to be embroidered is strained perpendicularly upon a rectangular frame, of which the vertical sides F F are shown in the steel engraving, and the horizontal sides F′F′. The piece to be embroidered is wound upon two rollers G G, whose ends, mounted with iron studs, are supported upon the sides F of the frame so as to turn freely; small ratchet wheels g' g' at the ends of these beams allow the piece to be stretched between them. (See Fig. 847.) There are also two central beams furnished with ratchet wheels g g at their extremities. As it will be seen by Fig. 847 that the two beams are not in the same vertical plane, the plane of the web would be presented obliquely to the needles, were it not for a straight bar of iron G′ G′, round the edges of which the cloth passes, and is thus made vertical. The two upper rollers present the web to the upper row of needles, and the two lower rollers present it to the lower row of needles. The piece is kept stretched crosswise by small brass templets, to which the strings y' are attached, and by which it is pulled towards the sides of the frame F. The pantograph for shifting the web into all the required posi-

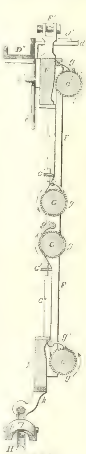
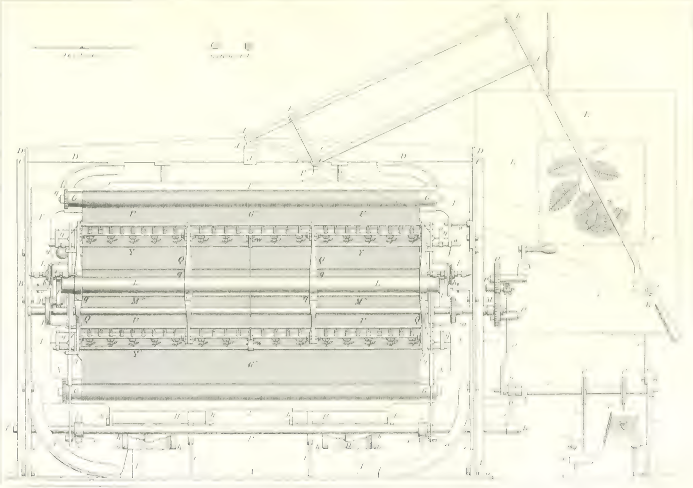


Fig. 847.


D
G
P
Y
Q
q
L
M
H

tions is arranged in the following manner:—$bb'fb''$ is a parallelogram, the four angles of which are jointed in such a way as to be made very acute or very obtuse at pleasure, while the sides remain of the same length; the sides bb' and bb'' are prolonged, the one to the point d, and the other to the point c, and these points c and d are chosen under the condition that in one of the positions of the parallelogram the line cd which joins them, passes through the point f; this condition may be fulfilled in an infinite variety of ways, since the position of the parallelogram remaining the same, it is evident that if we wish to shift the point d further from the point b', it would be sufficient to bring the point c nearer to b'', or *vice versâ*; but having once fixed upon the distance $b'd$, it is clear that the distance $b''c$ is its necessary consequence. Now, the principle upon which the construction of the pantograph rests is this: it is sufficient that the three points b, f, and c be in a straight line in one only of the positions of the parallelogram, in order that they shall remain always in a straight line in every position that can be given to it. If the side bb'' has been made equal to the sixth part of bc, ff' will also be one-sixth of cc; that is to say, the lines described by the point f will be exactly the sixth part of those described by the point c. [See PANTOGRAPH.]

The side bc is furnished with a handle B'', with which the workman moves the suspended web into the positions required. In order that this may be done with precision, the sides of the pantograph are joined so that the middle of their thickness lies exactly in the vertical plane of the web, and that the axes of the joints are truly perpendicular to this plane, in which, consequently, all the displacements are effected. This result is attained by making fast to the superior great cross bar D'' an elbow piece d'', with a projection to which is adapted in its turn the piece d', which receives in a socket the extremity of the side db; this piece d' is made fast to d'' by a bolt, but it carries an oblong hole, and before screwing up the nut, the web is made to advance or recede till the fulcrum point comes exactly into the plane of the web. The frame is then attached to the angle f of the parallelogram by means of the piece F''. (See Fig. 847.)

Now, if the workman take the handle B'' in his hand, and make the pantograph move in any direction, the point f will describe a figure similar to that described by the point c, but six times smaller; but the point f cannot move without the frame and the web mounted upon it moving also. Thus, in the movement of the pantograph, every point of the web describes a figure exactly similar to that described by the point f, and consequently similar to that described by the point c, but six times smaller; the embroidered object being produced upon the cloth in the inverse position of that of the pattern. It is, therefore, sufficient to give the man who holds the handle B'' a design six times larger than that which is to be executed by the machine, and to afford him a sure and easy means of tracing over with the point c all the outlines of the pattern. For this purpose there is adapted to c, perpendicularly to the plane of the parallelogram, a small style terminated by a point; the pattern is fixed upon a vertical tablet E, parallel to the plane of the stuff and of the parallelogram, and distant from it only by the length of the style: this tablet is carried by the iron rod e' secured to a cast-iron foot E'. The frame, loaded with its beams and cloth, is very heavy; and as it must not be allowed to swerve from its plane, it must be lightened so as to enable the operator to cause the point of the pantograph behind c to pass along the tablet without any straining or uncertainty in its movements. For this purpose, a cord e, attached to the side bc of the pantograph, passes over a return pulley, and carries at its extremity a graduated weight, which equipoises the pantograph, and tends slightly to raise the frame. The upper part I' of the framework carries two projecting rods L'' (see also Fig. 847), furnished with a longitudinal slit, in which the bolt i'', moving with slight friction, also serves as a guide to keep in its place the upper part of the frame. The lower part of the frame carries two horizontal rods H H, each attached by two arms hh, bent a little on one side, both of which are engaged in the grooves of a pulley H'. (See the engraved plate, and also Fig. 847.) By means of this mechanism, a regulated pressure can be exerted upon the frame from below upwards; and without preventing the frame from moving in all directions, it hinders it from deviating from the primitive plane to which the pantograph was adjusted. The lengths of the rods H ought to be equal to the amount of the lateral movement of the frame. Two guides ii, supported by two legs of cast-iron, present vertical slits in which the lower part of the frame F is engaged.

3. The two carriages, one on each side of the web, are similar. (See Fig. 850.) Each carriage is a long hollow cylinder of cast-iron I, carrying at either end two grooved castors or pulleys L', which roll upon the horizontal rails K; the pulleys are mounted upon a forked piece l', with two ends to receive the axis of the pulleys, and the piece l' itself is bolted to a projecting ear l, cast upon the cylinder. (See Fig. 849.) Thus each carriage rests in stable equilibrium upon the rails K, and may be easily moved backwards and forwards, so as to pass or draw the needles through the cloth. Each carriage is usually moved by its own attendant; but the man who works the pantograph can, by turning the handle N in one or other direction, cause the carriage to approach to, or recede from the web. For this purpose a pulley J is attached to the uprights A C, A' B', only one of which is shown on the side A' B', it being omitted on the side A C in order to show the toothed wheel m. At the height of the pulleys J is an axis M'', bearing towards each of its extremities a toothed wheel m; this axis is prolonged on the left side for the purpose of carrying another toothed wheel M. Upon the pulley J, and on the toothed wheel m, corresponding thereto, is an endless chain so arranged that on turning the axis M'' in one direction, the carriage is brought up to the web, and in turning it in the other direction, it is removed therefrom.

When one carriage has advanced so as to pass the needles into the stuff, the other carriage is present to receive them: it seizes the needles with its pincers, pulls them through, and then withdraws in order to stretch the thread and close the stitch: it then goes back with the needles and inserts them into the web in its turn. During these movements the first carriage remains at its post, waiting the return of the second, so that the two carriages make in succession an advance and a return, but they never move together. To produce these movements there is attached to the piece of wood made fast to the two uprights A C and A D of the frame, a bent lever, *n* O, movable round the point O, and carrying the toothed wheels O′ O″; the four wheels M M′ O′ O″, have the same number of teeth, and the same diameter; the two wheels O′ O″ are so fixed that on turning the handle N the wheel O″ revolves, and consequently the wheel O′; when the lever *n* O is vertical, the wheel O′ touches neither the wheel M nor the wheel M′; but if it be inclined to one side or the other, it brings the wheel O′ alternately into gear with M or M′. As the man has both hands occupied, the one with the pantograph and the other with the handle N, his feet are employed for acting on the lever *n* O, for which purpose two pedals are provided, and thus he performs with his feet a series of operations no less delicate than those which he executes with his hands. The pedals P are movable round the axis *p*, and carry cords *p*′ wound in an opposite direction upon the pulleys P′, which are fixed upon a movable shaft P″, supported upon one side by the prop E′, and on the other in a piece K′ attached to the two great uprights of the frame. On depressing the pedal, which is shown raised in the figure, the upper part of the shaft P″ will turn from the left to the right, and the lever *n* O will become inclined so as to carry the wheel O′ upon the wheel M′; but, at the same time, the pedal which is now depressed will be raised, because its cord will be wound up upon its pulley as much as the other cord has been unwound; and thus the machine will be ready to act in the opposite direction when required to do so.

4. At regular intervals of about half a metre upon the shaft L, are the appendages *q q*, upon which are fixed by two bolts the curved branches Q, which carry the mechanism of the pincers, which will be understood from the following figures. T, Fig. 848, is the lower jaw of one of the pincers mounted on a prismatic bar S, and fixed thereto by a screw *t*. Above this screw a spring *t*′ serves to raise the hinder limb of the upper jaw V (shown detached in Fig. 848) and thus to force the short limb into contact with the lower jaw. About the middle are two small ears pierced with a hole, and separated from each other by an interval equal to the thickness of the upper jaw, and destined to receive the corresponding ear *v* of this jaw. A little to the right of the ears is a small vertical projection *t*″, whose function is to stop the needle, if from any cause it tends to advance too much. To the right is also a thin plate T′, pierced with a conical hole, larger outside than inside.

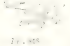


Fig. 848

The lower jaw being in its place, the upper jaw is so arranged as to make it pass a pin traversing the three ears, in order to raise the pincers. The pincer is naturally closed by the operation of the spring *t*′, and it cannot be opened except in operating from above downwards upon the tail of the upper jaw V, with a pressure capable of overcoming the elasticity of the spring *t*′.

The needle is shown in the steel engraving, of the natural size, and also at V′ Fig. 849. It is pointed at both ends, and the eye is in the middle, as already stated. The silk thread is passed through it as in an ordinary needle, but is not doubled; the free end of the thread is unravelled, and then secured by being twisted by the action of the finger and thumb.

When a pincer is open, and one-half of the needle is inserted into the opening of the plate T′, it is then lodged in an angular groove, which is less deep than the needle is thick, so that when the pincers are closed, the upper jaw presses it into the groove, and the needle is firmly held, although touched at only three points of its circumference.

Suppose all the pincers to be mounted at proper distances, (varying with the kind of ornament on different webs,) in the prism S, and forming the upper range as in the steel engraving, the workman opens all the pincers at once to enable them to receive the needles which have been planted in the web by the opposite carriage. For this purpose an axis of iron U, a section of which is shown in the steel engraving, and in section Fig. 849, is supported by the forks *u*, at the extremity of the branches Q, and held by the pin *u*′: the axis is round in the parts where it rests in the forks, and these are of such a weight that when the flat portion of the bar is turned down it only touches the tails of the upper jaw V, Fig. 849, of the pincers, without pressing them, and the pincers remain closed; but when this axis is turned a little round it presses on the tails of the pincers, and opens them by overcoming the elasticity of the springs *t*′. The axis U is turned round by means of two toothed sectors at the end, working in a vertical bar, also toothed and sliding against the branch Q.

The man can also open and shut the pincers by operating with his feet upon the pedals P. The axis P″ in the steel plate, set in motion by these pedals, carries at its extremity on the right a piece *p*″ which acts on the lever *n* O, which, being toothed on two-thirds of its circumference, performs the office of a pinion. This toothed portion engages a sector *r* on the extremity of an axis R, which turns upon itself, and is supported by projections *r*′ *r*′ fixed to the middle of the lower horizontal bars of the frame. A rack attached to this axis works into the upright, which is toothed at the lower end, and this upright acts upon the iron bar U as already explained.

The threads get stretched in proportion as the carriage is run out, but as this tension has no elastic play, too much force and consequent rupture is prevented by adapting to the carriage a mechanism, by means of which all the threads are pressed at the same time by a graduated weight. A little below the prismatic bar which carries the pincers, is a shaft Y, carried by pieces *y* fixed to the arms Q, in which it can turn. At its left it carries two small bars, *y'* and *w'*, Fig. 849, and at its right a single bar *y'*, and a counterweight. The ends of the two bars *y'* are joined by a straight iron wire. When the carriage approaches the web, and before the iron wire can touch it, the small bar *w* presses against a pin *w'*,

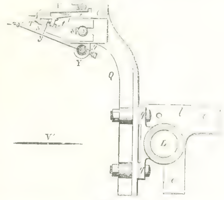


Fig. 849.

which rests upon it, and tends to raise it more and more; the bars *y' y'* and the iron wire are lifted up at the same time, and take the position shown in Fig. 850, but when the carriage, setting out from this position,

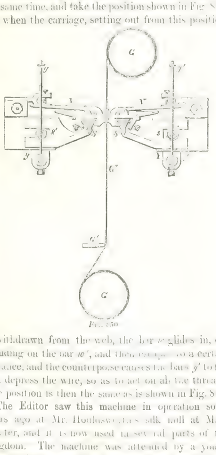


Fig. 850

is withdrawn from the web, the bar *w* glides in, descending on the bar *w'*, and then escapes to a certain distance, and the counterpoise causes the bars *y'* to fall and depress the wire, so as to act on all the threads. The position is then the same as is shown in Fig. 849.

The Editor saw this machine in operation some years ago at Mr. Houldsworth's silk mill at Manchester, and it is now used in several parts of the kingdom. The machine was attended by a young woman who managed the pantograph, and two children who regulated the motions of the carriages. A piece of black velvet was being embroidered with flowers. Much care is required in the management of the pantograph. The operative must not follow slidingly with the point of the style the trace of the design upon the tablet, but must rest the point of the style upon the point of the pattern into which the needle is to be inserted, then remove it, and put it down again upon the point by which the needle ought to re-enter in coming from the other side of the piece; and so on in succession. To assist these manipulations, the pattern in the tablet is composed of right lines terminated by the points for the entrance and return of the needle, so that the operative has continually under her eyes the series of broken lines which must be followed by the pantograph. If she quit this path for an instant, without having left a mark of the point at which she had arrived, she must look at the web to see what has been already embroidered, and thus ascertain the point at which she must resume her work, so as not to leave a vacant space, or repeat the same stitch.[1]

EMERALD. (Italian, *Smeraldo*, from the Greek, Σμαράσσειν, to shine, to be bright.) This precious stone, which ranks next to the diamond, and is equal to oriental ruby and sapphire, is of a beautiful green colour. It occurs in prisms, with a regular hexagonal base; sp. gr. 2·7; it scratches quartz with difficulty, and is scratched by topaz, and fuses before the blowpipe into a frothy bead. Its analysis has been differently stated by different chemists; but it appears to contain about 14 per cent. of glucina, (which is its characteristic constituent,) 68 of silica, 16 of alumina, and a very small portion of lime and iron: it also contains less than 1 per cent. of oxide of chromium, to which it owes its colour. The paler varieties of this stone are known under the name of BERYL: they are coloured by oxide of iron. *Aquamarine* includes clear beryls of a sea-green, or pale bluish, or bluish green tint.

The finest emeralds come from Grenada, where they occur in dolomite. A crystal from this locality, in the cabinet of the Duke of Devonshire, measures in its greatest diameter 2⅜ths inches nearly; its lesser diameter barely 2 in.; its third diameter 2¼th in.: the extreme length of the prism is 2 inches. It contains several flaws, and is therefore only partially fit for jewellery; it has been valued at more than 500 guineas. A more splendid specimen, weighing 6 ounces, belonging to Mr. Hope, cost 500*l*. Both these specimens are exhibited in the Great Exhibition. Emeralds of less beauty, but of very large size, occur in Siberia. One specimen in the imperial collection of Russia measures 1½ inches in length and 12 in breadth. Another is 7 inches long and 4 broad, and weighs 6 lbs.

The finest beryls (*aquamarines*) come from Siberia, Hindostan, and Brazil. In the United States very large beryls have been obtained, but seldom transparent crystals: they occur in granite or gneiss. A reputed beryl of large size mentioned in most books on mineralogy has recently been discovered to be a lump of quartz.

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(1) The embroidering machine is described in the Bulletin de la Société Industrielle de Mulhausen, No. 38. Tome viii. 1835.

Euclase and *chrysoberyl* contain glucina as a characteristic, and belong to this group.

EMERY, a mixed granular corundum, extensively used in the arts for grinding and polishing metals, glass, &c. The use of emery in the arts is of very ancient date, as is proved by the existence of works on hard stones, which could not have been executed except by the use of emery, or of minerals of that nature. It is probable that some of the localities of emery which have recently been discovered were known to the ancient Greeks and Romans. Thus, the locality of Gumuch-dagh is near the ancient Magnesia, on the Meander, and between Ephesus and Tralles, twelve miles from each of these cities, and the same distance from Tyria, in all which cities the arts flourished, especially the art of cutting hard stones, if we may judge from the specimens which have been transmitted to modern times. The quantity used was, however, very small compared with what it now is, especially since plate-glass has become so common.

During several centuries, down to within the last two or three years, the island of Naxos, in the Grecian Archipelago, was the only source for the supply of emery. This kind is often known under the name of *Smyrna* emery, from the fact of its coming to us from that port. Its price at the end of the last century was from 7*l*. to 8*l*. 10*s*. per ton; and between the years 1820 and 1835, even less than this. About this period, the monopoly of the Naxos emery was purchased from the Greek government by an English merchant, who so regulated the quantity given to commerce, that the price gradually rose from 7*l*. to 30*l*. per ton, a price at which it was sold in 1846 and 1847. About this time, however, Dr. J. Lawrence Smith, an American mineralogist, being at Smyrna, saw some specimens of emery ore from a place twenty miles north of that port, which had been discovered through the agency of a knife-grinder of the country, who had been in the habit of using it to charge his wheels with. The importance of this circumstance to the Turkish government, as well as to the arts, induced Dr. Smith, in 1847, to examine the supposed locality of this mineral. An English merchant named Healy also pointed out other localities of the mineral. The first locality examined was that of Gumuch-dagh, a mountain about twelve miles east of the ruins of Ephesus, and composed of bluish marble resting on mica slate and gneiss. On the very summit of the mountain the emery was found scattered about, and projecting above the surface of the soil. In was in great profusion, in angular fragments of a dark colour, and in large masses of several tons' weight. On penetrating the soil, the emery was found imbedded in it, and a little further down it was come to in the rock. By breaking the marble that projects above the surface at this spot, nodules of the mineral were found. In some places the emery formed almost a solid mass, several yards in length and breadth, the spaces between the blocks being filled with an earth highly charged with oxide of iron. In other places the masses were consolidated by carbonate of lime of infiltration, which must not be confounded with the emery in its original gangue (the marble), in which it is found in nodules, sometimes round, and at other times fissured so as to represent angular fragments. In no place did it present anything like a vein, nor had it signs of stratification The largest unbroken mass seen by Dr. Smith must have weighed from 30 to 40 tons.

Other localities of emery are Kulah, Adula, and Manser; also the island of Nicaria, in the Grecian Archipelago. In the island of Naxos the emery is found in large blocks mixed with a red soil, and also imbedded in white marble. It is taken principally from the north and east side of the island: the best comes from Vothric, nine miles from the shore, and is embarked at Sulionos. Another good locality is at Apperanthos, seven miles from the shore, and it is embarked at a small port called Montzona. In the south of the island it is found near Yasso. It is in such abundance on this island that, notwithstanding the immense quantity carried off, it has not yet been found necessary to quarry the rock.

Dr. Smith having reported his discoveries to the Turkish government, a commission of inquiry was instituted, and the business soon assumed a mercantile form. The monopoly of the emery of Turkey was sold to a mercantile house in Smyrna, and since then the price has diminished in the English market to from 10*l*. to 15*l*. the ton. The different mines explored are those of Naxos, of ancient date; of Kulah, commenced in 1847, and now abandoned for those nearer the sea; of Gumuch-dagh, commenced in 1847, and worked largely; and of Nicaria, commenced in 1850. From all these different places the emery is sent to Smyrna, and from thence principally to England, the vessels taking it at a very low price, as it serves for ballast. The various mines belong to the Turkish and to the Greek governments. The latter now sells its emery in lots of several tons; but as the former has sold the entire monopoly of its mines, the operations are controlled by a single interest: but it is expected that this monopoly will be abolished in virtue of a commercial treaty existing between Turkey and the other powers. The effect of this will be greatly to reduce the price of emery.

Of the different varieties of emery used in the arts, that of Naxos is still preferred, as it is more uniform in its quality than that from Kulah and Gumuch; but if the best qualities of Nicarian emery are found in abundance, and such only sent to the market, they will prove equal, if not superior, to the emery of Naxos.

The mining of emery is of the simplest character. The natural decomposition of the rock in which it occurs facilitates its extraction. The rock decomposes into an earth in which the emery is found imbedded. The quantity procured under these circumstances is so great that it is rarely necessary to explore the rock. The earth in the neighbourhood of the block is almost always of a red colour, and serves as an indication to those who are in search of the mineral. Sometimes, before beginning to excavate, the spots are sounded by an iron rod with a steel point, and when any resistance is met with, the rod is rubbed in contact with the resisting body, and the effect produced on the point enables a practised eye to decide whether it has been done by emery or not. The blocks which are of a convenient size are transported in their natural state, but are frequently broken by large hammers: when they resist the action of the hammer, they are subjected to the action of fire for several hours, and on cooling they most commonly yield to blows. It sometimes happens that large masses are abandoned, from the impossibility of breaking them into pieces of a convenient size, as the transportation either on camels or horses requires that the pieces shall not exceed 100 lbs. each in weight.

At Kulah, the quantity of emery detached from the rock was not very considerable, as it had been protected from decomposition by the beds of lava that cover it. There the marble was quarried to get at the emery, which was done in 1847 with profit, although the emery had to be carried 110 miles on the backs of camels. Since the diminution of the price of emery, this mine has been abandoned, for the quarrying into the marble was found very difficult, the tools used in boring, &c. being thrown out of use in a very short time by the pieces of emery encountered at every instant. At the time when Dr. Smith wrote, all the emery sent from Asia Minor was from the mine at Gumuch-dagh.

Emery appears to be a mechanical mixture of corundum and oxide of iron: that from Naxos is of a dark grey colour, with a mottled surface, and with small points of a micaceous mineral disseminated in the mass. It frequently contains bluish specks or streaks, which are easily recognised as being pure corundum. The emery from the other localities has each its own peculiar aspect. The fracture of emery is tolerably regular, and the exposed surface granular: it is exceedingly difficult to break when not traversed by fissures, or not of a lamellated structure. When reduced to powder, it varies in colour from dark grey to black. The colour of its powder affords no indication of its commercial value. The powder examined under the microscope shows the distinct existence of the two minerals, corundum and oxide of iron. Emery when moistened always affords a very strong argillaceous odour. The specific gravity is about 4. Its hardness is its most important property in its application to the arts, and was ascertained by Dr. Smith in the following manner: Fragments are broken from the piece to be examined, and crushed in a diamond mortar with two or three blows of a hammer, then thrown into a sieve (with 100 holes to the square centimetre). The portion passing through is collected, and that remaining on the sieve again crushed, and so on until all the emery had passed through the sieve. The powder is then weighed, and the hardness tested with a circular piece of glass, about 4 inches in diameter, and a small agate mortar. The glass is first weighed, and placed on a piece of glazed paper: the pulverized emery is then thrown upon it at intervals, rubbing it against the glass with the bottom of the agate mortar. The emery is brushed off the glass from time to time with a feather, and when all the emery had been made to pass once over the glass, it was collected, and passed through the same operation three or four times. The glass was then weighed, again subjected to the same operation, the emery by this time being reduced to an impalpable powder. This series of operations is continued until the loss sustained by the glass is exceedingly small. The total loss in the glass is then noted, and when all the specimens of emery are submitted to this operation under the same circumstances, an exact idea of their relative hardness is obtained. The advantages of using glass and agate are, that the latter is sufficiently hard to crush the emery, and in a certain space of time to reduce it to such an impalpable state that it has no longer any sensible effect on the glass; and, on the other hand, the glass is soft enough to lose during this time sufficient of its substance to allow of accurate comparative results. By this method, the best emery was found capable of wearing away about half its weight of common French window-glass. The blue sapphire of Ceylon, pulverized and experimented with in this manner, wears away more than four-fifths of its weight. This furnished the standard of comparison.

The following Table shows the results of the examination of ten specimens of emery:—

No.	Localities.	Effective Hardness, Sapphire 100.	Specific Gravity.	Chemical Composition.					
				Water.	Alumina.	Oxide of Iron.	Lime.	Silica.	Total.
1.	Kulah	57	4.28	1.90	63.50	33.25	0.92	1.61	101.18
2.	Samos	56	3.98	2.10	70.10	22.21	0.62	4.00	99.03
3.	Nicaria	56	3.75	2.53	71.06	20.32	1.40	4.12	99.43
4.	Kulah	53	4.02	2.36	63.00	30.12	0.50	2.36	98.34
5.	Gumuch	47	3.82	3.11	77.82	8.62	1.80	8.13	99.48
6.	Naxos	46	3.75	4.72	68.53	24.10	0.86	3.10	101.31
7.	Nicaria	46	3.74	3.10	75.12	13.06	0.72	6.88	98.88
8.	Naxos	44	3.87	5.47	69.46	19.08	2.81	2.41	99.23
9.	Gumuch	42	4.31	5.62	60.10	33.20	0.48	1.80	101.20
10.	Kulah	40	3.89	2.00	61.05	27.15	1.30	9.63	101.13

Other substances in very minute quantities occur in some of the emeries, as titanic acid, oxide of manganese, oxide of zirconium, and sulphur. Those emeries which contain the least water, everything else being alike, are the hardest. The silica is usually in combination with alumina, or the oxide of iron, or both; [illegible] must not always be [illegible] the quantity of corundum in the emery.[1]

We come now to describe the various methods adopted in this country for preparing emery for the manufacturer and the mechanic.[2] In the ordinary process, the lumps of emery ore as they are imported are broken up, as the [illegible] is for repairing macadamized roads, and into lumps of similar size. These lumps are then crushed under stampers, such as are used for pounding metallic ores, driven by water or by steam power. It is supposed that the stampers leave the fragments more angular than they would be if ground under runners, a mode which is sometimes employed. The coarse powder is then sifted through sieves of wire-cloth, which are generally cylindrical, like the bolting-cylinders of corn-mills; but the sieves are covered with wire-cloth, having in general about 90 to 16 wires to the inch. The following figures show the numbers of wires usually contained in the sieves, and the names of the kinds respectively produced by them:—16. Corn emery; 24. Coarse grinding emery; 36. Grinding emery; 46. Fine grinding emery; 58. Super grinding emery; 60. Coarse flour emery; 70. Flour emery; 80. Fine flour emery; 90. Superfine flour emery. No. 16 sieve gives emery of about the size of mustard-seed; and coarser fragments, extending nearly to the size of peppercorns, are also occasionally prepared for the use of engineers. The sieves have sometimes as many as 120 wires in the inch; but the very fine sizes of emery are more commonly sifted through lawn sieves. The finest emery that is obtained from the manufacturers is that which floats in the atmosphere of the stamping-room, and is deposited on the beams and shelves, from which it is occasionally collected. The manufacturers rarely or never wash the emery: this is mostly done by the glass-workers, opticians, and such others as require a greater degree of precision than can be obtained by sifting.

Washing-over, or *elutriation*, as the process is called by chemists, is a beautiful application of the law of gravitation to the useful arts.[3] Thus the alluvial deposits of some of the tropical rivers are washed in order to separate the particles of gold which they contain. A small portion of the mud of the river is stirred in a large quantity of water contained in a broad shallow basin, the gold, being many times heavier than the earthy particles, quickly subsides, and the mud, which remains suspended for a long period in the water, is removed by pouring off the water from the valuable sediment. In a similar manner the particles of emery and other powders may be separated according to their magnitudes, in a more accurate manner than can be accomplished by sieves. A portion of emery-powder of uncertain size is thoroughly well mixed in a large quantity of water, as in a common wash-hand basin, and at the end of 10 seconds the liquid is poured off from the sediment which has fallen down in that period; the sediment is laid aside in a separate vessel. The bulk is again stirred and poured off at 10 seconds, and this second sediment added to the first, which process is repeated until no further sediment is deposited in the period of 10 seconds; the process requires watchfulness and a steady hand. A fresh deposit is similarly collected from the residue after a longer period of rest, say 20 seconds, until the whole quantity of emery is divided into grains of so many sizes, as may be required for the particular branch of manufacture for which it is intended. Mr. Holtzapffel states, that for many years he used emeries in the construction of mechanism of twelve degrees of fineness, part of them prepared by himself, by washing-over, namely:—No. 1. Corn emery of commerce; No. 2. Grinding emery; No. 3. Fine grinding emery; No. 4. Superfine grinding emery; all prepared by sifting: No. 5. Deposited at the end of two seconds; No. 6, at the end of five seconds; No. 7, ten seconds; No. 8, twenty seconds; No. 9, sixty seconds; No. 10, three minutes; No. 11, fifteen minutes; No. 12, sixty minutes. The emeries of the sizes 5 to 12 are preserved in glass bottles, to keep them pure.

In the preparation of emery for optical purposes, Mr. Ross mixes 4 pounds of the flour emery of commerce, with 1 ounce of powdered gum arabic, and then throws the powder into 2 gallons of clear water. He collects deposits, as above described, at the end of 10 seconds, 30 seconds, 2 minutes, 10, 20, and 60 minutes, and that which is not deposited by 1 hour's subsidence is thrown away as useless for grinding lenses. The use of the gum arabic, which renders the water slightly viscid, was recommended by Dr. Green for preparing red oxide of iron, for polishing specula.

Another mode of preparing emery was pointed out some years ago by Mr. Hawkins. That gentleman finding that the emery sold in the shops was inadequate to the purpose of grinding two flat surfaces of hard cast steel accurately, thought of applying to emery a process which he had seen for washing over diamond dust. To ensure a good hard quality of emery, he procured of an emery-maker a quantity of those small lumps or grains which had longest withstood the action of the cast-iron runners and bed: these pieces were reduced to powder in a cast-iron mortar and then separated into different portions by sieves. The finest emery thus obtained was washed over with oil instead of water, the oil holding it in suspension a much longer time, and in this way he obtained a series of emeries which had floated 1, 5, 10, 15, 20, 40, and 80 minutes, amongst which he found every variety necessary for his purpose, and keeping them in boxes which were numbered according to the minutes they had floated, he could at any time prepare more of any one kind. In this way Mr. Hawkins readily attained his object, and by selecting those grains of emery which resisted longest the action of the pestle and mortar, he obtained some so hard as to be capable of cutting a ruby when employed instead of diamond dust.

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[1] [illegible] J. L[illegible] Smith, M.D. Read [illegible] Institute, July 15, 1[illegible], and [illegible] American Journal of Science and Arts [illegible]

[2] [illegible] chiefly derived from Holtzapffel's Mechanical [illegible] vol. iii.; Nicholson's [illegible] Technological Re[illegible]

[3] [illegible] BALL, the manufacturer [illegible].

Mr. Gill, by grinding Greek emery-stone between two flat and hard steel surfaces and washing off the lighter portions in oil, found that those which subsided in half a minute, when examined by a microscope, had entirely resisted the friction, and were perfectly crystallized sapphires.

Mr. Chezy prepared very fine emery for optical purposes in the following manner:—After having well ground the coarse emery on an iron plate with an iron muller, it is thrown into a vessel which must be rather wider at bottom than at top by a gradual increase. The vessel must then be filled with clear water, so that it may stand 8 or 10 inches above the emery. The whole is then strongly agitated with an iron spatula and left to settle for an hour. The short branch of a syphon is then introduced to the depth of 4 inches below the surface, and the turbid water withdrawn without disturbing the vessel. The water thus drawn off is received into another large vessel, and the first vessel is again filled and its contents agitated as before. The same operation is repeated until the water flows clear through the syphon. The powder collected in the second vessel is too fine for grinding glass. The vessel being emptied and cleared, the same operations are to be repeated, but the water is to be drawn off at the end of half an hour, until the water passes clear through the syphon. The emery thus obtained by subsidence, is preserved for use under the denomination of *emery of half-an-hour*. The same operation being repeated, allowing only a quarter of-an-hour for subsidence, gives a fine emery, but not so fine as the preceding; this is known as *emery of a quarter-of-an-hour*. In this way emeries may be obtained of ½ or ¼ of a minute.

Washing emery by hand as above explained, is far too tedious for those who require very large quantities of emery, such as the manufacturers of plate glass and some others, who generally adopt the following method:—Twelve or more cylinders of sheet copper, of the common height of about 2 feet, and varying from about 3, 5, 8, to 30 or 40 inches in diameter, are placed exactly level, and communicating at their upper edges, each to the next, by small troughs or channels; the largest vessel has also a waste-pipe near the top. At the commencement of the process, the cylinders are all filled to the brim with clean water; the pulverized emery is then churned up with abundance of water in another vessel, and allowed to run into the smallest or the 3-inch cylinder, through a tube opposite the gutter leading to the second cylinder. The water during its short passage across the 3-inch cylinder, deposits in that vessel such of the coarsest emery as will not bear suspension for that limited time; the particles next finer, are deposited in the second or the 5-inch cylinder, during the somewhat longer time the mixed stream takes in passing the brim of that vessel; and so on. Eventually the water forms a very languid eddy in the largest cylinder, and deposits therein the very fine particles that have remained in suspension until this period; and the water, lastly, escapes by the waste-pipe nearly or entirely free from emery. In this simple arrangement, *time* is also the measure of the particles respectively deposited in the twelve or more vessels, their number being determined by the quantity of sizes respectively required in the manufacture to which the emery is applied. When the vessels are to a certain degree filled with emery, the process is stopped, the vessels are emptied, the emery is carefully dried and laid by, and the process is recommenced.

Emery-paper is prepared by brushing the paper over with thin glue, and dusting the emery powder over it from a sieve. There are about six degrees of coarseness. Sieves with 30 and 90 meshes per linear inch, are in general the coarsest and finest sieves employed. When used by artizans, the emery-paper is commonly wrapped around a file or a slip of wood, and applied just like a file, with or without oil, according to circumstances. The emery-paper cuts more smoothly with oil, but leaves the work dull.

Emery-cloth only differs from emery-paper in the use of thin cotton cloth instead of paper, as the material upon which the emery is fixed by means of glue. The emery-cloth when folded around a file, does not ply so readily to it as emery-paper, and is apt to unroll. Hence smiths, engineers, and others, prefer emery-paper and emery-sticks; but for household and other purposes, where the hand alone is used, the greater durability of the cloth is advantageous.[1]

Emery-sticks are rods of deal about 8 to 12 inches long, planed up square, or with one side rounded like a half-round file. Nails are driven into each end of the sticks as temporary handles, they are then brushed over one at a time with thin glue, and dabbed at all parts in a heap of emery-powder, and knocked on one end to shake off the excess. Two coats of glue and emery are generally used. The emery-sticks are much more economical than emery-paper wrapped on a file, which is liable to be torn.

Emery-cake consists of emery mixed with a little suet chopped small, rendered down, and mixed with a very little bees'-wax, so as to constitute a solid lump, with which to dress the edges of buff and glaze wheels. The ingredients should be thoroughly incorporated by stirring the mixture whilst fluid, after which it is frequently poured into water, and thoroughly kneaded with the hands, and rolled into lumps before it has time to cool. The emery-cake is sometimes applied to the wheels whilst they are revolving; but the more usual course is, to stop the wheel, and rub in the emery-cake by hand. It is afterwards smoothed down by the thumb.

Emery-paper, or *Edwards' patent razor-strop paper*, (patented in 1843,) is a new article, in which fine emery and glass are mixed with paper pulp, and made into sheets as in making ordinary paper. The emery and glass are said to constitute together 60 per cent. of the weight of the paper, which resembles drawing-paper, except that it has a delicate fawn colour. This emery-paper is directed to be pasted or glued upon a piece of wood, and when rubbed with a little oil, to be used as a razor-strop.

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[1] H. Edwards' patent for emery-cloth was taken out in December [illegible]

Barclay's artificial emery-stone. In 1842, Mr. Henry Barclay took out a patent for a method of combining powdered emery into disks and laps of different kinds, suitable to grinding, cutting, and polishing glass, enamels, metals, and other hard substances. The process of manufacture is as follows:—Coarse emery-powder is mixed with about half its weight of pulverized Stourbridge loam and a little water or other liquid, to make a thick paste; this is pressed into a metallic mould by means of a screw-press, and after having been thoroughly dried, is baked or burned in a muffle or close receiver at a temperature considerably above a red heat, and below the full white heat. In this case, the clay or alumina serves as a bond, and unites the particles very completely into a solid *artificial emery-stone*, which cuts very greedily, and yet seems hardly to suffer perceptible wear.

Superfine grinding emery is formed into wheels exactly in the same manner as the above, but the proportion of loam is then only one-fourth instead of one-half that of the emery. These emery-stones, which are of medium fineness, cut less quickly, but more smoothly than the above.

Flour-emery when manufactured into artificial stones, requires no uniting substance, but the moistened powder is forced into the metal mould and fired; some portions of the alumina being sufficient to unite the whole. These fine wheels render the works submitted to them exceedingly smooth, but they do not produce a high polish on account of the comparative coarseness of the flour-emery. Stourbridge loam is not the only ingredient used in uniting the particles of emery. Many other substances answer as well; such as slate, Yorkshire gritstone, crocus, &c.; and in this way the hardness and cut of the emery-stone may be varied to a great extent. Most of the grinders made of the emery-stone are formed with central holes, so as to admit of being attached to the lathe upon appropriate chucks or spindles; and the substance is so porous as to absorb much water, which is gradually thrown to the surface by the centrifugal motion, so as to keep the edge conveniently moist, or with excessive velocity the water is thrown off as in trundling a mop. Mr. Barclay has made the disks of various diameters, from ½ inch to 8 or 10 inches diameter, but the difficulty increases with the size, as the large ones are liable to warp and crack in the firing. When the emery-stone laps are required to have plane surfaces, angular or convex edges, &c., that could not be readily moulded, the composition is partially fired at a low heat, then turned in a lathe to the proper form, and fired at nearly a white heat. The coarse emery-stone has been used, it is said, successfully, in glass-cutting.

Common Corundum is much used in the East as an abrasive. Like emery, it owes its valuable property to the highly crystalline alumina of which it mostly consists. The lapidaries in India use corundum-wheels by cementing powdered corundum with one-third by volume of lac-resin. The corundum-powder is put into an earthen vessel and heated over a clear fire, and when hot enough to fuse a piece of resin easily, the resin is stirred in, in small portions at a time. The mass is then taken out and beaten with a pestle upon a smooth stone, then rolled upon a stick, re-heated several times, and continually kneaded until a uniform mixture is produced. It is then separated from the stick, laid again upon a stone slab previously covered with very fine corundum-powder, and flattened into the form of a wheel by an iron rolling-pin. The wheel is then polished by a plate of iron and corundum-powder, and lastly a hole is made through the middle by a heated copper or iron rod. These wheels are made with a grain more or less fine. The coarser perform the first rough work, and the finer cut the stones, which are moistened and sprinkled with corundum-powder. These wheels are mounted on a horizontal axis, and the workman sitting on the ground, makes them revolve with a spring bow held in his right hand, while the stone to be cut is held in his left. The polish is given by wheels of lead and very fine corundum-powder.

Corundum-rubbers are made by melting lac, and then intimately mixing corundum-powder with it. The composition is then moulded in the shape of a brick of about 6 by 4 inches, and 1½ inch deep, with a handle of wood about 6 inches long at the end, having a rise of about 30° for the convenience of working it. For coarse rubbers the proportions are, by weight, lac 8, corundum 1; for the medium, lac 12 to 16, and corundum 1. The fine rubber is made by mixing the grindings of agates, carnelians, and the like with lac, and as the wheels upon which they are ground are made of corundum and lac, the grindings must contain a portion of those materials. A good proportion is 6 lac to 1 grindings.

Mr. Holtzapffel states that some dentists employ old files thinly coated with a cement of emery and shell lac in finishing enamel or mineral teeth.

ENAMEL AND ENAMELLING. An enamel is a vitreous substance used for painting on glass, porcelain, &c., and for covering metals with various kinds of useful and ornamental work. When the painting is complete, or the metal is covered, adhesion is produced by exposing the article to a temperature sufficiently high to fuse the enamel. Hence there are several conditions which enamels are required to fulfil: they must be fusible at a certain moderate temperature; they must adhere strongly to the glass, porcelain, or metal to which they are applied; they must have a certain transparency or opacity, such as will enable the artist to produce the effects of a finished picture; they must preserve a smooth vitreous appearance after fusion, and be sufficiently hard to resist the friction of solid substances; they must be insoluble in water and also resist the action of the atmosphere; and lastly, they must contract and expand to the same extent as the substances which they cover.

In the present article we shall confine our attention chiefly to the enamelling of metals, referring to the article POTTERY AND PORCELAIN for some details respecting *enamel-painting*.

Enamels are composed of colouring-matters, which for the most part consist of metallic oxides, and, secondly, of fluxes, or vehicles for the colour, consisting of vitrifiable substances, such as silicates, borates, or boro-silicates, in different proportions. The colour of an enamel results either from the colour of one of its constituents, or is a result of the chemical combination of the constituents: in the one case, the colouring-matter is simply mixed with the flux, or, if the flux combine with it chemically, it does not affect its colouring property; in the other case, the flux has a chemical action on the colouring-matter.

Gold, silver, and copper are the metals which are usually enamelled. The enamels used for the purpose must have their point of fusion below that of the metals to which they are applied; it must be higher for copper and silver than for gold. They must be very fusible when used alone; but when they form a ground for other enamels, they must be capable of resisting a high temperature without fusing.

Enamels are opaque or transparent: those which are used as a ground are opaque; those which are used in painting may be transparent or opaque, but the latter are usually preferred, especially for silver and copper.

Enamelling on metals is more difficult than on glass and porcelain. The presence of an oxidizable metal usually produces a reaction between the two bodies: the enamel dissolves the oxide which forms on the surface of the metal at a high temperature, and becomes coloured thereby; or the enamel may itself oxidize the metal, in consequence of the oxide of lead contained in it, in which case the lead is reduced, and the colour is destroyed. Hence gold admits of being enamelled better than copper and silver; but if gold contain copper, some difficulties may be experienced. On copper and silver the enamel generally undergoes some change, at least in the layer which is in contact with the metal. If the enamel is transparent, the defects are apparent; but if opaque, and the surface smooth, the defects are concealed. Copper and silver are sometimes first covered with an opaque enamel, and afterwards with one that is transparent.

The objects to be enamelled are usually prepared for the purpose by the jeweller. They may be entirely or only partially covered with enamel, according to the design. In the one case there must be a projecting edge to retain the enamel, and in the other, certain hollows engraved according to the design.

All the enamels which are applied to metals have a vitreous, transparent, colourless base. The following are recipes for transparent enamels:—

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Silica	3 parts	3 parts	[illegible] parts	[illegible] parts	3 parts
Minium	3 —	4 —	5 —	[illegible] —	[illegible] —
Nitre	2.5 —	2 —	1 —	1 —	0 —
Borax	0 —	1 —	1 —	1 —	1 —

Opacity is given to enamels by the addition of a certain proportion of—1, oxide of tin, 2, phosphate of lime, or 3, oxide of antimony. The oxide of tin is first combined with the oxide of lead before the enamel is made. For this purpose, metallic lead and tin are fused together, and raised nearly to a red heat; the oxide which forms on the surface is removed as fast as it is formed; heat is again applied, to render the oxidation more complete. It is next stirred up in water to precipitate the minute portions of metal which have escaped oxidation, and in this way the oxide can be separated.

The proportions of tin and lead which have to be thus fused together vary according to the composition of the enamel into which these oxides enter. A quantity of oxide of tin equal to about one-tenth of the weight of the enamel will render it of an opaque white. The proportion of lead is variable according to the kind of enamel required. For this purpose the following alloys will be found useful:—

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Lead......	[illegible] parts	[illegible] parts	[illegible] parts	6 parts	[illegible] parts
Tin	1 —	1 —	1 —	1 —	1 —

In the following recipes for opaque enamels, the oxide of one or other of these alloys is used instead of the oxide of lead in the transparent enamels:—

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Silica	[illegible] pts.	3 pts.	[illegible] pts.	[illegible] pts.	[illegible] pts.
Alloy (No. 1) [illegible] (No. 2)	[illegible]	5 —	[illegible]	[illegible]	(No. 5) 7 —
Nitre	2.5	2 —	1 —	1 —	1
Borax	0 —	1 —	1 —	1 —	1 —

The above enamels are those adapted to gold. The more fusible enamels required for copper and silver may be formed by the addition of one-tenth of their weight of calcined borax. By the further addition of this substance the fusibility of enamels may be increased at pleasure.

Coloured enamels may be formed either opaque or transparent, by melting up with any one of the above enamels a certain proportion of some metallic oxide, as indicated in the following recipes:—

		Parts.
Blue enamel.—Take opaque or transparent enamel ..		[illegible]
	Oxide of cobalt	1 to 2
Green enamel.—Opaque or transparent enamel ..		[illegible]
	Oxide of chromium	[illegible] 2
Another green.—Opaque or transparent enamel ..		[illegible]
	Binoxide of copper	1 to 2
Violet enamel.—Opaque or transparent enamel ..		[illegible]
	Peroxide of manganese	1 to 2
Yellow enamel.—Opaque or transparent enamel ..		[illegible]
	Chloride of silver	1 to 2
Purple enamel.—Opaque or transparent enamel...		[illegible]
	Purple of Cassius	[illegible] 2
Black enamel.—Transparent enamel		1
	Oxide of copper, oxide of cobalt, and oxide of manganese, 1 to 2 parts of each.	

Recipes for enamels used in painting on porcelain will be given in the article POTTERY AND PORCELAIN.

The enamels which are applied to metals are ground up with water in an agate mortar, and kept ready for use under water in a covered vessel. The metals to be enamelled must be made perfectly clean by being boiled in a solution of potash, and then washed in pure water. If gold be alloyed, it ought to be boiled may be [illegible] of 10 parts [illegible] and 35 sea-salt. This will remove the copper from the surface, and enable the enamel to make contact with pure gold.

A tolerably complete idea may be formed of the art of enamelling by the following detail of the processes concerned in the manufacture of watch-dial plates, which are manufactured in considerable numbers in this country. Enamelled dial-plates are of two kinds: the *hard*, in which the surface is covered with hard or Venetian enamel, and the *soft*, in which English soft glass enamel is used. The metals best adapted for the basis of the plate are fine gold or fine copper: the latter is most common, and is known by the name of *enamellers' copper*. The copper must be very thin, or the plates will crack in firing. The copper, having been cut into squares of the proper size, is heated to redness in a clear fire: when cold, the squares are formed into the intended shape of the dial. The tools required by the enameller are as follows: 1. The *dies*, one of which is shown in section in Fig. 851: these are small circular plates of brass, about $\frac{1}{25}$th inch thick: their edges are turned a little conical, and their centres perforated with holes nearly as large as those to be made in the dial-plates. The enameller has about forty of these, from $\frac{3}{4}$ inch to $2\frac{1}{4}$ inches in diameter. 2. A round-ended punch, Fig. 852, made of steel wire about $\frac{3}{16}$ths inch thick and $1\frac{1}{2}$ long, fixed in a convenient handle: it is used for the purpose of punching up the copper in the centre-holes of the dies. 3. A clock-maker's round broach, Fig. 853, firmly fixed in a strong handle: its use is to burnish up an edge to the copper, and also to square up the centre-holes. 4. A die or block, Fig. 854, to set the copper of the desired concavity: this is of box or other hard wood, and a little larger in diameter than the largest brass die: it has a hole through the centre something wider than the hole in the dial-plate. 5. A large pair of scissors, for cutting the copper into shape. 6. A setting spatula, Fig. 855, made of steel wire about $\frac{3}{16}$ths inch in diameter and 5 inches long, with one end beaten flat and thin, then filed a little round, and the flat part bent so as to form a segment of a circle somewhat smaller than the curve of the setting-die: the outer part of the curve should then be smoothed on an oil-stone. 7. A smooth needle-makers' file, used for filing the plated wire and the edge of the copper after it has been burnished up to the edge of the brass die. 8. A small steel point, rather stouter than a stocking-needle, used for marking the place where the feet of the dial should be put.

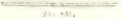


Fig. 851.

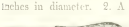


Fig. 852.

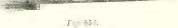


Fig. 853.

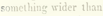


Fig. 854.

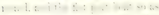


Fig. 855.

9. A large soldering-lamp, Fig. 856, of the capacity of at least a quart: it has a cylindrical spout for the wick, at least $1\frac{1}{2}$ inch in diameter. 10. A pair of tweezers. 11. A blow-pipe for soldering the feet upon the coppers: the hole must be a little more open than is usual in blowpipes. 12. A watchmaker's glass and dial-gauge. 13. A pair of nippers, to cut the feet from the plated wire.

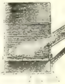
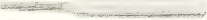


Fig. 856.

Supposing the workman finds, on measuring the frames of the watches which are to be furnished with dial-plates, that the frame corresponds with one of the divisions on the gauge, he selects a die half a size larger, as the dial must always be one size larger than the frame, including the thickness of the copper. The dial, when completed, ought to extend over the frame just enough to fill the groove in the inner case of a watch, turned for that purpose. If the dial is to be made to a brass edge, the die should be fully one size less than the inner rim; for as the dial has to lie within the rim of the edge, an allowance must be made for the thickness of the copper, and also for the swelling of the plate in the fire. The proper die being chosen, one of the pieces of copper must be placed on that side of the die which has the smallest diameter, and as nearly in the centre as possible; the die with the copper upon it is then placed flat on a table or board, and the round-headed punch, Fig. 852, being put in the centre, it is pressed down and worked round till the end of it is forced as far as it can go into the centre hole of the die. The copper is then taken off, and the bulge thus formed filed nearly through. The copper is then placed on the die in the same manner as before, and the round broach gently thrust through the centre hole till it fits it nearly tight to the die. Then holding the die and copper in the left hand with the die upwards, the copper is cut as nearly round as possible, leaving it about $\frac{1}{30}$th inch larger than the smallest side of the die, which is done by holding the scissors a little aslant. The die, with the copper uppermost, is then to be laid on the work-board, and gently rubbed or burnished over with the round broach, till the copper lies quite smooth and flat on the die. Then holding the die and the copper firmly in the left hand, and having the broach in the right, that part of the copper is to be burnished which extends beyond the edge of the die; this is best done by rubbing the broach round the copper and pressing it close to the edge of the die. The copper is now to be taken off the die, and the edge or rim thus formed is finished by filing it till it is equal on every side. The centre hole must be filed a little to take off the ragged parts, but it must not be made so low as the edge, and the bur that is formed by filing must be scraped off with the edge of a graver. The copper is then set up to the desired convexity by placing it in the setting die, and rubbing it with the setting spatula till the copper touches in all parts. After this, the feet are soldered on; for which purpose, copper wire plated with silver is very preferable to plain copper wire soldered with spelter. When the copper is set up properly, it is placed on the frame of the watch, then holding the copper and the frame in the left hand, the holes in the frame where the feet are to be placed are marked with the point or needle. The copper is then placed in the setting die, and small squares are described about each of the marks that have been made with the point, large enough to admit the foot wire to be placed within, the object of the squares being to throw up a bur or ridge to prevent the foot from slipping out of its place during the operation of soldering. The feet for the coppers are cut by fixing an iron peg into the work-board, and the pieces of plated wire being held against it, it will form a very good resistance to the action of the file. If coppers are to be made for flat plates, the feet should be filed at right angles; but if the plates are convex, they should be filed at an angle, as nearly as possible corresponding with the curve formed in the hollow part of the copper, because when the foot is placed on the copper it will be found to stand perpendicular to the base line or edge of the copper. The feet thus filed are cut off with the nippers; if for frame plates, about $\frac{3}{16}$ths inch long; but if for flat plates, about [illegible]th will be sufficient. A small quantity of borax is next rubbed upon a piece of slate with the addition of a few drops of water, into which the filed parts of the feet being slightly dipped will greatly assist the soldering. The copper is then held in the left hand, and the feet, taken up with the tweezers, are set in their proper places on the copper preparatory to soldering, which is done by placing the copper on a piece of charcoal and directing the flame of the lamp by means of the blow-pipe upon it, until the copper is nearly at a white heat; the silver solder then runs down to the copper and completes the soldering. If the feet have kept in their places, they will fit into the holes of the frames, but if they have shifted a little, the copper must be placed in the setting die with the feet upwards, and the frame being held over the feet, they must be bent into the proper direction, by introducing the setting spatula between the frame and the copper, until they fit into the holes of the frame. The copper is then to be gently withdrawn from the frame, and if any dents or bulges have been made, they must be removed by putting the copper into the setting die, and rubbing the spatula round the feet till such imperfections are removed. Lastly, the copper is cleaned in a dilute solution of nitric acid, then washed in clean water with a soft brush and a little white sand. If the scale is completely removed, they need not be again pickled in the acid.

The tools used in enamelling are, 1. An agate pestle and mortar to grind the enamel. 2. A small riveting hammer. 3. A flat spatula, [illegible] inch broad and a little thicker than those used for painters' knives. 4. A spatula rather thicker than the last, but of equal breadth; one side of this is flat and the other a little curved. It must be of good steel, and is used to spread the hard enamel on the copper. 5. A spatula, Fig. 557, for spreading the hard enamel on the under



side of the copper; this is called the bottom spatula; it is similar to the setting spatula, but curved at the end. 6. A quill cut like a tooth-pick, for clearing the enamel out of the centre holes. 7. Two damask napkins for drying the water from the enamels. 8. A small basin with a cover to hold the enamel used for the tops of the dial-plates. 9. A gallipot to hold the enamel that is used for the bottoms. 10. A cylindrical block of wood to fix the copper on when it is ready to have the enamel laid on the top. This for common sized plates may be about 1½ inch in diameter and 6 inches long. Soft wax is fixed at one end of this, so as to form a kind of cap to the block. 11. A box or tray to hold the plates when the enamel is spread on them. It may be about 16 inches long, 9 broad and 1½ deep. 12. A small steel-faced anvil to hold in the hand to break the enamel on. The face may be about 1 inch in diameter.

The soft glass enamel, which is bought by the enameller, in cakes, is prepared by [illegible] on the [illegible]. It is [illegible] broken up [illegible] face of the hammer, any parts coloured with black and red streaks being rejected, as they would contaminate the whole of the enamel. When it is broken up into fragments, not larger than small peas, it is carefully ground with water in the agate mortar, and the fine powder into which it is gradually reduced, is washed away four or five times during the grinding, by filling the mortar with clean water, and agitating the enamel with the broad flat spatula, stirring it up from the bottom, till the water appears quite milky: the enamel should then be allowed to settle to the bottom, and the water poured off. Great care must be taken to keep off specks of dirt, as these will form specks on the surface of the dial-plates. The grinding must be continued, until the enamel is reduced to the fineness of fine grain gunpowder; although, for some purposes, it need not be finer than maw-seed. When completely ground, and [illegible] water, the enamel is kept under water in the covered basin, until ready for use.

The Venetian hard enamel that is used for bottoms, is broken up with the hammer, and then crushed in a cylindrical iron mortar, with a pestle fitting into it. Having been pounded until it is as fine as the glass enamel, it is ground in the agate mortar, to an almost impalpable powder. This enamel is not to be washed, as the flour is in this case of use. When the enamel is ground, it is kept under water ready for use, for if allowed to get dry after being ground, it must be washed up again in the agate mortar, otherwise it is likely to blister in the fire.

The Venetian hard enamel, such as is to be used for the faces or tops of dial-plates, is selected with care, so that the colour may be pure. It is then placed on a piece [illegible], and heated to redness; it is to be suddenly quenched in very clean spring-water, which will cause it to split up into very small pieces, which are ground in the agate mortar. The enamel is broken up in this way, to avoid using the hammer and steel pestle, because, if a small particle of steel gets into the enamel, it will do mischief. The flour separated during the washings is allowed to subside, and is added to the gallipot with that which is used for bottoms. When the enamel is ground sufficiently fine, it is kept in a wide-mouthed glass bottle with a glass stopple, and covered with strong nitrous acid.

All these preparatory steps being taken, we now proceed to show, first, the method of enamelling with soft glass enamel. A napkin is laid on the work-board, four times doubled: the copper is to be held in the left hand with the feet upwards, and a small quantity of the hard enamel for bottoms is taken out of the gallipot on the end of the bottom spatula, and spread roughly on the copper, covering it closely up to the feet and centre holes. It is then laid between the folds of the cloth, till a little of the water is absorbed, when it must be smoothly spread, with the convex side of the spatula. If too much of the water be not removed, the enamel can be easily spread from the parts where it lies thickest to those that are too thin, until a general evenness is produced. It must then be smoothly spread by drying it more with the napkin, and spreading it again with the spatula, pressing more lightly as the enamel gets dry. The centre hole must be cleared out by twisting the quill in it, and the operation of laying the bottom is then completed.

A clean napkin is next folded and placed on the board, so as to hang over the edge about three or four inches, a weight being put on it, to prevent its being dragged down. When the wax upon the laying-block has been softened and made of a shape fit to receive the copper, the latter must be placed evenly on, and the feet pressed into the wax, till the under enamelled surface of the copper nearly touches it. Or this is better done by placing the setting block on the copper and pressing it down, for in this way the shape of the copper is preserved, and the upper side secured from the perspiration of the hands, which might cause the enamel to blister. The copper is next brushed clean with a soft hair brush, or a hare's foot, taking care not to leave any of the hard enamel on the surface, or about the edge. The block with the copper on it is now to be held in the left hand, and a small quantity of the glass enamel is to be taken upon the end of a flat spatula, and laid upon the copper near the centre hole, taking care not to let the water pass through the centre hole, as that would take the enamel from the bottom, which could not be replaced without injuring the enamel on the top, and so the two kinds would get mixed, and both be spoiled. When a sufficient quantity of the glass enamel has been put upon the copper, it must be roughly spread, by repeatedly indenting the edge of the flat spatula into the enamel, crossing it in all directions till it lies of a uniform thickness all over the copper. The inequalities thus formed on the surface may be reduced by just tapping the side of the block two or three times with the edge of the spatula. The water which this operation will cause to flow on the surface of the enamel, must be dried a little with the corner of the cloth, but not so much as to render the enamel difficult to be moved. The side, or part of the enamel which is too thick, must be reduced, by removing a portion of it to places that appear deficient. This is done by spreading the spatula over the enamel, turning the block round with the fingers and thumb of the left hand, till it lies generally even. It is then dried again with the napkin, and the surface made smoother by passing the spatula over it in all directions, bearing a little harder on the enamel as it gets drier. As this rubbing and spreading of the enamel will attract the moisture to the surface, and prevent the enamel from lying smoothly, it must be dried again and laid by, passing the spatula lightly over the surface. In determining the thickness of the enamel, allowance must be made for its more bulky, granulated state, previous to melting. In enamelling the tops of convex plates, the *shoulder*, which is about one quarter of the distance from the edge to the centre, should be laid somewhat thicker than towards the edge, because the edge being lower than the centre, the enamel, when in a fluid state in the fire, will flow down to it, and thus produce an equality of thickness on all parts of the copper. When the copper is covered, it must be carefully removed from the block, by gently raising it with the back of the thumb-nail, under the edge, and as near each of the feet as possible. It is then to be placed in the covered tray and kept from dust, till wanted for firing.

In hard enamelling, the copper, made chemically clean, is fixed on the laying block as before, and a coat of soft enamel first laid on, about two thirds of the thickness of that used in soft enamelling. This must be fired till the enamel is melted down to a tolerably smooth surface, and when cold, should any specks of dirt appear, they must be cut out with the point of a square graver whetted to a very obtuse angle. The plate must then be put for a short time into a solution of nitrous acid, just strong enough to cleanse the scale from the edge of the copper: it must then be washed in clean water. The plate is next fixed on the laying block, the wax being made soft enough to admit the feet without any great pressure. A small quantity of hard enamel, thoroughly purified of the acid by washing in several waters, must next be spread equally over the whole surface of the plate, and the corner of a clean napkin laid upon it to absorb a portion of the water. The enamel can then be spread more equally over the surface of the plate: when nearly smooth and of equal thickness, it must be dried again and the spreading be continued for ten minutes, rubbing it evenly in every direction till it is compressed as closely as possible.

The next process is *firing*, by which the enamel is melted into a uniform mass on the surface of the copper. The apparatus used is a ring for supporting the edge of the dial while in the fire, so that the feet may not come in contact with any substance, or they would be lowered. These rings are made of 1 part pipeclay and 2 parts black-lead. To prevent the adhesion of the enamel to the ring, one part of the ring is made like the frustum of a very obtuse-angled hollow cone, while the other side forms a plane perpendicular to the sides of the cylindrical parts. The dial being laid in the hollow side will just touch it at the part where the copper is bare, and thus prevent the adhesion of the enamel, especially if this part of the ring be first rubbed with fine whitening. When the dial is placed on the ring, both are set on a flat circular stone or a slab of Stourbridge clay, and as the dial must be kept turning in the fire during the whole time of melting in order to be equally heated, the slab with the ring and dial upon it are set upon a small piece of clay moulded into the segment of a sphere 5 inches in diameter. The enamellers call this arrangement a *turner*: it is shown in section Fig. 358, in which A is a curved dial for a watch without a brass edge; B the ring; C the slab or *planch*, and D the turner.

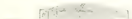


Fig. 358.

The furnace being sufficiently heated, the enamelled plates must be laid upon the hearth on a ring of proper size, and they are left until the moisture is entirely evaporated. The planch having been raised to nearly a white heat in the fire, is withdrawn, and the plate and ring set on it as nearly as possible in the centre: when the whole is to be placed on the turner under the muffle and kept in motion until it assumes one uniform surface. It must then be withdrawn with the tongs, and another treated in the same way, till the whole day's work is fired: this may vary from three to six dozen plates.

It seldom happens that a plate will come out of the fire free from small black or green specks. The union of so many small particles will also produce an unpleasing mottled appearance. The specks must be removed by a sharp graver. The centre hole of the copper and also the edge will appear to rise above the surface of the enamel: these are to be carefully filed down, and the plate is then ready for *using off*, *i.e.* rubbing the surface on a gritstone with fine sand and water until the glazed appearance is removed, and a uniform rough surface is produced. This removes the mottled appearance and gives a more equal convexity to the plate. It also removes the semi-transparent appearance of the enamel, and greatly increases its intense whiteness, and beautiful opacity. After the using off, the plates are brushed with a stiff hair brush and wet sand, then washed in clean water, and dried. They are now ready for the finishing fire.

The holes left in picking out the specks are filled up with the finest enamel, almost as fine as flour, and the plate being placed in a proper sized ring, is set on the iron hearth of the furnace, gradually bringing it nearer to the fire until it attains such a heat as will permit it to be placed in the hottest part without danger of cracking. The ring and plate are then lifted upon the planch with the tongs, and kept in motion until a white heat is attained. This being done, it must be taken out of the fire and blown upon with the breath for a few seconds and immediately returned to the heat: this will bring out a beautiful gloss and a degree of whiteness not attained by other means. The proper effect being produced, the plate must be withdrawn and set to cool gradually. If free from specks, the plate is ready for the next process: if specks exist, they can only be removed with the graver, (omitting the using-off,) and the firing must be repeated.

In firing hard enamel dials, the heat must not be so great, and the plate must be taken from the fire as soon as the enamel is found to form a tolerably compact body.

The hours, &c. are painted on the dial in a soft black enamel prepared for the purpose. It is ground very fine in an agate mortar, and mixed with oil of spike lavender until sufficiently diluted. A mark is made with a file on the edge of the dial, to indicate the place of number XII. Then, with the assistance of a division plate and its index, the divisions are slightly traced from the centre with a black lead pencil. The circular lines which contain the divisions of the hours, minutes, &c. are previously traced with compasses, one point of which is furnished with a cone, and the other with a port-crayon and pencil. When the painting is perfectly dry, the dial is once more fired.

The foregoing details contain most of the processes of the enameller. In ornamental enamelling, when the enamel is not intended to cover the whole surface of the plate, it is necessary to form a lodgment for it. The outlines of the design are therefore first drawn upon the plate with a black-lead pencil, and then traced with a graver. The spaces enclosed within the outlines of the design must then be deepened by proper tools, equal to the height which would have been given by the ridge or border had the plate been intended to have been enamelled all over. This deepening is effected with a flat graver; and it must be everywhere of equal depth, for if any raised portions be left, the enamel falls away, or is so thin in those parts as to show the metal through. The bottom of the lodgments for the enamel must be slightly hatched or roughened with the end of a small riffler file, broken square across, for the purpose of affording a hold to the enamel. The plate is then thoroughly cleaned, and is next covered with a coat of white enamel laid upon it wetted with water, much skill being required to bring the enamel into

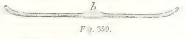


Fig. 359.

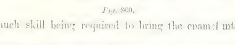


Fig. 360.

contact with the ridges or borders of the design. The spatula used in spreading the enamel is shown in two positions, a and b, Fig. 859. A form of tongs used by enamellers is shown in Fig. 860.

In some cases the design is produced by stamping a steel die upon a gold strip, and the hollows thereby produced are filled up with differently coloured enamels by means of a steel point. This method calls for the display of much skill and taste on the part of the enameller. The enamels are mixed with water or with oil of lavender, according to circumstances; several layers are usually applied, the object being fired between the application of every two layers.

Previous to firing, the plate is laid upon a piece of sheet iron, Fig. 861, pierced with small holes, and put upon hot ashes to expel the moisture, and to raise it to the proper temperature for introducing it into the muffle; [illegible], it would cause the enamel to fly off.

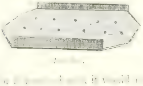


Fig. 861.

The enamelling of cast-iron vessels and other hollow ware for saucepans, &c., is an art which was introduced in the year 1799, and again in 1839. In the latter case, large sums of money have been expended in perfecting the processes, taking out patents and contesting the patent right. In the former year, Dr. Hickling obtained a patent for a process for lining iron vessels, &c. by fusion with a vitrifiable mixture, of which there were four kinds:—

The *first* was composed of 6 parts calcined flints, 2 parts of *composition* or Cornish stone, 9 parts of litharge, 6 parts of borax, 1 part of argillaceous earth, 1 part of nitre, 6 parts of calx of tin, and 1 part of purified potash.

The *second* consisted of 8 parts of calcined flints, 8 red lead, 6 borax, 5 calx of tin, and 1 of nitre.

The *third*, 12 of potter's composition, 8 borax, 10 white lead, 2 nitre, 1 white marble calcined, 1 argillaceous earth, 2 purified potash, and 5 calx of tin.

The *fourth*, 4 of calcined flint, 1 potter's composition, 2 nitre, 8 borax, 1 white marble calcined, ½ argillaceous earth, and 2 calx of tin.

Each composition to be finely powdered, mixed, and fused: when cold, the resulting vitreous mass is to be ground, sifted, and levigated with water. It is next mixed up with water or gum-water, and brushed over the interior of the vessel to be coated, and then fused in a muffle.

The fusibility of the coating is to vary according to the heat which is to be applied to the vessel when in use. For this purpose the proportions of the siliceous and fluxing materials were varied. The use of lead in this process is very dangerous, and ought on no account to be allowed.

In May 1839, Messrs. Clarke obtained a patent for coating iron saucepans, in such a way as to prevent the enamel from cracking or splitting from the effects of fire. The vessel is first cleaned with dilute sulphuric acid, then boiled in pure water. The composition is next applied. This consists of 100lbs. of calcined ground flints and 50lbs. of borax calcined and finely ground: the mixture to be fused and gradually cooled. 40lbs. of this mixture is then ground with water with 5lbs. of potter's clay, into a pasty mass, such as will form a coat on the inner surface of a vessel about ⅙ inch thick. This coating is *set* by putting the vessel in a warm room. The second coating or glazing is then applied. This consists of 125lbs. of white glass without lead, 25lbs. of borax, 20lbs. of soda in crystals, all pulverized together and vitrified by fusion, then ground, cooled in water, and dried. To 45lbs. of this mixture 1lb. of soda is to be added; the whole mixed in hot water, and when dry, pounded. A portion of this powder is sifted finely and evenly over the internal surface of the vessel while the first coating is still moist. The vessel is dried in a stove at the temperature of 212°: next heated gradually in a kiln or muffle until the glaze fuses. The vessel is then taken out and glaze powder is dusted over the glaze already in fusion, and the vessel is again heated. This makes the enamel smoother and sounder than can be obtained by a single application.

In consequence of Messrs Kenrick of West Bromwich sending into the market enamelled saucepans of cast-iron, Messrs. Clarke instituted legal proceedings against them; but they were not able to maintain their patent right in a court of law.

Dr. Ure gives the following dimensions for an oven or muffle used for coating metals with enamel:—"The outside 8 feet square with 14-inch walls; the interior muffle 4 feet square at bottom, rising 6 inches at the sides, and then arched over; the crown may be 18 inches high from the floor; the muffle should be built of fire-brick 2½ inches thick. Another arch is turned over the first one, which second arch is 7 inches wider at the bottom, and 4 inches higher at the top. A 9-inch wall under the bottom of the muffle at its centre divides the fire-places into two, of 16 inches wide each, and 3 feet 3 inches long. The flame of the fire plays between the two arches and up through a 3-inch flue in front, and issues from the top of the arch through 3 holes about 4 inches square. These open into a flue 10 × 9 inches, which runs into the chimney.

"The materials for the enamel body (ground flint, potter's clay, and borax) are first mixed together and then put into a reverberatory furnace, 6 feet 6 inches long by 3 feet 4 inches wide and 12 inches high. The flame from an 18-inch fire-place passes over the hearth. The materials are spread over the floor of the oven about 6 inches thick, and ignited or fritted for 4 or 5 hours, until they begin to heave and work like yeast, when another coating is put on the top, also 6 inches thick, and fired again; and so on the whole day. If it be fired too much, it becomes hard and too refractory to work in the muffles. The glaze is worked in an oven similar to the above. It may be composed of about one-half borax and one-half of Cornish stone in a yellowish powder procured from the potteries. This is baked for 10 hours and then fused into a glass which is ground up for the glaze."[1]

Before concluding this article we must notice the art of enamelling by the lamp, by which small articles are modelled from tubes and rods of glass, and of enamel of various sizes and colours.

The enameller's table is represented in Fig. 862, arranged for four workmen. Below is a large pair of double bellows B, set in action by the foot of one of the men for the purpose of producing a blast from a tube, which acting on the flame of each lamp after the manner of a blowpipe, lengthens it and contracts it into a narrow point, the heat of which is very great. Below the table, and in its thickness, are grooves covered with parchment, which serve to conduct the blast to glass tubes placed opposite each lamp. These tubes or blowpipes A A are of glass, curved at their upper ends so as to direct the blast into the middle of the flame; and they are adjusted by being held in a perforated cork, which exactly fills and closes the hole in the table. When only one person is at work, he sits before the lamp, which is close to the pedal of the bellows, all the other blowpipes being removed and the holes closed with corks. A shade of tin plate is placed over the flame to shield the man's face from the heat and glare, the tip of the flame being left visible; and by day the apartment is made obscure, because the man can work with more precision by the light of his lamp than by the mixture of artificial and natural light. When at work, he holds in his left hand the work to be executed, or the iron or brass wires which serve to support the figure: he then conducts with his right hand the thread or bead of enamel softened by the flame of the lamp.

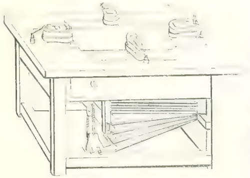


Fig. 862.—ENAMELLER'S TABLE.

The manipulations of the enameller cannot well be described. They are the result of much practice, which ought to be directed by good taste. The glass and enamelled toys which are usually sold, are sadly deficient in taste, however much we may admire the manual skill with which they are produced. As an example of this kind of work, suppose the enameller is about to form a swan. He takes a tube of white enamel, closes one end of it with the flame of the lamp, and when sufficiently heated, he blows it into a kind of bottle, to which he gives the shape of the body of the bird: he then lengthens and bends the neck, forms the head, the beak and the tail; after which, with a small rod of enamel of the proper colour, he makes the eyes; lastly he opens the beak, forms the wings and feet, and the rude resemblance of a swan is finished.

Far more beautiful and satisfactory is the production of that elegant substance known as *spun-glass*, which the enameller makes in the following manner:—He takes a slip of plate-glass and makes it red hot: he then draws it out into a thread with pincers and attaches it to a reel, which he moves rapidly round, holding the slip of glass all the time in the point of the flame. In a short time a skein of glass is formed of great fineness and of the lustre of satin. By using rods of different colours the glass threads may be varied in a beautiful manner. A tuft of spun-glass fixed upon a point upon the prime conductor of an electrical machine in action is a striking object.

The enameller also makes artificial eyes, and if skilful he will so imitate the colours of the natural eye that it is difficult to distinguish it from the real one in a person wearing it.

The reader who desires a more intimate acquaintance with this subject, is referred to the works quoted below, which we have consulted in the preparation of this article.[2] See also APPENDIX.

ENCAUSTIC TILES, see POTTERY & PORCELAIN.

ENDOSMOSE and EXOSMOSE, see CAPILLARY ATTRACTION, Cyc. See also DIALYSIS, App.

ENGINE, a compound machine, including one or more of the mechanical powers, as levers, pulleys, screws, &c. Its object is to raise, cast, or sustain any weight, or produce any effect which could not otherwise be readily accomplished. The word is said to be derived, through the French, from the Latin *ingenium;* because of the ingenuity required in the contrivance of engines to increase the effect of moving powers.

The word MACHINE also signifies anything used to augment or to regulate moving forces or powers; or it is any instrument employed to produce motion, so as to save either time or force. The word is derived from *μηχανή*, *machine, invention, art;* and it is therefore properly applied to any agent in which these are combined, whatever may be the strength or solidity of the materials of which it is composed. The term *machine*, however, is commonly restricted to a certain class of agents which hold a middle place between TOOLS or INSTRUMENTS and the more complicated and powerful ENGINES.

ENGINEER AND ENGINEERING. Engineer is a term applied to those who are employed in devising or forming engines or machines, and in directing their applications. The duties of the engineer are divided

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(1) Supplement to Dictionary of Arts, Manufactures, &c. 1844.

[2] Nouveau Manuel complet de la Peinture sur Verre, sur Porcelaine et sur Émail, par M. F. E. Reboulleau. [illegible] Paris, 1844. Published in the collection of the Manuels Roret. Dictionnaire Technologique, Article, Émail, and the article Enamelling in Brewster's Edinburgh Cyclopædia. In the [illegible] vol. of the Transactions of the Society of Arts, will be found a paper by Mr [illegible] [illegible] Enamel, Colours and Fluxes, and the [illegible] therewith."

into *military* and *civil.* The duties of the military engineer (since everything relating to the service of artillery is now confided to a particular corps) comprehend the construction of fortifications, both permanent and temporary, including the trenches and batteries required in sieges; also of barracks, magazines, and other works connected with war. In France, the title of engineer is given to those who are engaged in trigonometrical surveying and in the practice of naval architecture. Thus the French have a corps of *ingénieurs géographes*, of *ingénieurs d'hydrographie*, and of *ingénieurs de marine*.

Military engineering will not occupy our attention in this work; but the various important branches and ramifications of civil engineering will be considered under their respective heads. The profession of the civil engineer, as defined in the Charter of Incorporation of the Institution of Civil Engineers, London, is, "The art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation, and docks, for internal intercourse and exchange; and in the construction of ports, harbours, moles, breakwaters, and lighthouses; and in the art of navigation by artificial power for the purposes of commerce; and in the construction and adaptation of machinery; and in the drainage of cities and towns." Civil engineering is both a science and an art: as a *science*, it includes the general principles of mechanics and construction; shows how we may ascertain the strains to which a structure is exposed; the dimensions and proportions which should be given to its several parts, so as to be able to resist such strains without injury. As an *art*, civil engineering shows how scientific principles may be applied to the construction of works, and how used and modified so as to meet the difficulties which constantly arise in practice.

The civil engineer, being concerned in almost every kind of construction, ought to be a highly accomplished man of science; and, indeed, there are few men in any profession who can command so large an amount of scientific and practical knowledge as the civil engineer. The following classified arrangement[1] of the several branches of civil engineering, with their subdivisions, will not only serve to show the extent of the subject, but will guide the student in pursuing a systematic scheme in the attainment of his professional knowledge.

Synopsis of the Science of Civil Engineering.

I. MENSURATION.

I. Surveying.—1. Description of instruments; their use and adjustment. 2. Surveying in general. 3. Trigonometrical surveying. 4. Hydrographical surveying. 5. Mining surveying.

II. Levelling.—1. Levelling instruments; their use and adjustment. 2. Practice of levelling. 3. Measuring heights with the barometer.

III. Drawing and Plotting.—1. Instruments for drawing and plotting; their use. 2. Plotting surveys, and making plans. 3. Plotting levels and making sections. 4. Preparing parliamentary plans and sections. 5. Preparing working and contract plans and sections. 6. Preparing detail drawings of works (bridges, &c.). 7. Making mechanical drawings. 8. Principles of projection, perspective, and shadows.

IV. Estimating.—1. Taking out quantities from drawings. 2. Measuring quantities from the works themselves. 3. Measuring artificers' work. 4. Calculating, measuring, and valuing earthwork. 5. Estimating value or cost of works.

V. Setting out Works.—1. Centre-lines and side-widths of railways, roads, canals, &c. 2. Setting out bridges, viaducts, walls, &c. 3. Setting out tunnels and driftways.

II. GENERAL CONSTRUCTION.

I. Statics.—1. Composition and resolution of pressures. 2. Moments of pressures. 3. Parallel pressures, and the centre of gravity.

II. Stability of Structures.—1. General conditions of stability. 2. Stability of polygonal framings. 3. Equilibrium of arches. 4. Stability of abutments and piers. 5. Stability of retaining walls. 6. Equilibrium of suspension bridges.

III. Strength of Materials.—1. To resist a tensile and crushing strain. 2. Elasticity and elongation of bodies subject to a tensile or crushing strain. 3. When subjected to a transverse strain. 4. Elasticity and deflexion of bodies subjected to a transverse strain. 5. To resist torsion.

IV. Materials employed in Construction.—1. Metals. 2. Timber. 3. Natural stones. 4. Artificial stones, including bricks, concrete, and the various cements used in masonry. 5. Materials for earthworks, such as embankments, puddled banks, dams, &c. 6. Materials for roads and pavements. 7. Materials for covering roofs.

V. Different Kinds of Construction.—1. Brickwork. 2. Masonry. 3. Forming Foundations. 4. Carpentry.

VI. Auxiliars employed in Construction.—1. Scaffolding, fixed and travelling. 2. Centerings. 3. Coffer-dams.

III. MECHANICS, OR CONSTRUCTION OF MACHINERY.

I. Dynamics.—1. Vis viva, momentum, and work. 2. Motion; uniform, accelerated, or retarded; gravitation. 3. Collision and impact of moving bodies. 4. Motion down inclined planes and curves. 5. Motion about fixed centres; centres of percussion, oscillation, and gyration.

II. Moving Forces.—1. Water as a mechanical agent. 2. Air as a mechanical agent. 3. Animal strength as a mechanical agent. 4. Heat as a mechanical agent; the steam-engine.

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(1) From Mr Law's "Rudiments of Civil Engineering," published in Weale's Rudimentary Series, 1850.

III. Resistances to Motion.—1. Friction. 2. Resistance of the medium through which the body moves.

IV. Theory of Machines.—1. Elements of machinery. 2. Teeth of wheels, racks, and pinions. 3. Transmission of work by machinery. 4. Determining the modulus of a machine in motion. 5. Mechanical expedients for transmitting or changing motion. 6. Proportioning the strength and dimensions of machinery.

V. Machines employed in Engineering.—1. Machines employed for transporting and raising materials, such as crabs, cranes, dredging-machines, &c. 2. Machines employed in actual construction, such as pile-driving engines, excavating machines, pumps, diving-bells, pug and cement-mills, &c. 3. Machines for working upon materials, as lathes, boring, planing, mortising, riveting, and screw-cutting machines, saws, &c. 4. Implements and tools for excavating, boring, working in wood, metals, stones, &c.

IV. SPECIAL CONSTRUCTION.

I. Common Roads.—1. Principles which should control the selection of route. 2. Laying out roads, and arrangement of gradients. 3. Construction of roads. 4. Draining roads. 5. Repair of roads. 6. Protecting their surface by different kinds of pavement.

II. Railways.—1. Principles which should determine the route, and the general arrangement of the curves and gradients. 2. Different systems of haulage; the locomotive, the atmospheric, and the rope. 3. Of the general construction of the railway. 4. Of the permanent way; different forms of rails, switches, &c. 5. Of draining the line, and maintaining the slopes and permanent way. 6. Arrangement of termini and stations. 7. Construction of engines and carriages. 8. System of working the line.

III. Canals.—1. Principles which should determine the choice of the line of a canal. 2. Arrangement of levels; number of locks, and form of section. 3. General construction of canals. 4. Arrangement of locks; means of saving water, and obtaining feeders. 5. Methods of propulsion, or towing, and resistance on canals. 6. Construction of aqueducts. 7. Repair and preservation of canals.

IV. Harbours and Docks.—1. On the construction of piers, breakwaters, and quay walls. 2. On the means of deepening harbours, by dredging or excavation. 3. Selection of site for docks, and their arrangement. 4. Construction and arrangement of locks, cast-iron and timber gates, sluices, &c. 5. Construction of dock walls.

V. Bridges.—1. Selection of site, and determination of the kind of bridge. 2. Construction of stone and brick bridges. 3. Construction of iron and timber bridges. 4. Construction of suspension bridges. 5. Construction of railway viaducts. 6. Of forming the foundations of bridges.

VI. Tunnels.—1. Determination of the form and dimensions of the tunnel. 2. Method of excavating and securing the ground. 3. Sinking shafts, and driving headings or drift-ways. 4. Method of draining the tunnel. 5. Subaqueous tunnels.

V. HYDRAULIC ENGINEERING.

I. Hydraulics.—1. The science of hydrostatics. 2. Hydrodynamics. 3. Pneumatics.

II. Drainage and Irrigation.—1. Drainage of open country and agricultural districts. 2. Improvement of outfall, and diversion of water from other districts. 3. Surface draining; catch-water drains, and under draining. 4. Drainage of bogs and marsh lands. 5. Of *warping* up, and reclaiming lands from the sea and rivers. 6. Drainage of towns. 7. Form, dimensions, and declivity proper for sewers. 8. Of the collection and disposal of the sewage.

III. Supply of Water to Towns.—1. Principles which should guide the choice of the means of supply. 2. Different sources of supply; from the water-shed of the country, from springs and Artesian wells, or from large rivers. 3. Means of estimating the quantity required, and of ascertaining the probable supply and the quality of the water. 4. Systems of supply; the *constant* or high-pressure system, and the intermittent. 5. Selection of site for reservoirs. 6. Construction of reservoirs. 7. Contrivances for raising the water to the level of the high reservoirs. 8. Of the means of filtering and purifying the water, and of the construction of the filter beds. 9. Of the motion of water in pipes, and their discharge.

IV. Marine Engineering.—1. Action of waves and currents; their modification by the contour of the shore, and the depth of water. 2. Their action on the shore, on beaches, on vertical, sloping, and curved walls, and generally on any obstacle. 3. On the *régime* of coasts, and their preservation. 4. Construction of sea-walls, embankments, breakwaters, piers, and other structures exposed to the action of the sea, more particularly as regards their form. 5. Principles which should determine the selection of the site for a harbour, and the arrangement of its form. 6. On the causes which produce shoals and bars. 7. Means of keeping harbours free from such obstructions, or of removing them where already existing. 8. On the improvement of harbours and sea channels.

V. Improvement of Rivers.—1. On the tidal wave at the mouth of rivers, and its modification in passing up the river. 2. Principle of the conservation of tidal force. 3. On the antagonist agencies of the tide and land waters in rivers, and the means of determining which of these should be assisted; of the *régime* of rivers. 4. On the form of the shore-line of rivers, and their improvement. 5. Of the junction of rivers. 6. On the velocity of the stream; its scouring and transporting power compared with the nature of its bed. 7. Effects of projections, irregularities, and obstructions, such as dams and weirs. 8. Of the formation and removal of shoals; their causes; of artificial scouring and sluicing. 9. Of the shoals formed at the mouths of rivers; their cause and prevention.

VI. SCIENCES COLLATERALLY CONNECTED WITH ENGINEERING.

I. Somatology, or the properties of matter.
II. Chemical Philosophy.
III. Geology and Mineralogy.
IV. Natural History.
V. Physical Geography and Hydrography.
VI. Mathematics.
VII. Acoustics.

Of all these sciences a certain amount of knowledge is required by the civil engineer; but of some more than others, depending, in a great measure, upon those particular branches of the profession to which he may more exclusively direct his attention.

ENGRAVING. The process of engraving is one in which the fine arts and the useful arts are equally brought into requisition. In the first place, there is the painting or finished drawing of which copies are to be made; this is the work of an individual mind—the result of the labour of individual hands: the genius of the artist has brought it into existence, and it is stamped at once, by the ideality displayed therein, as belonging to the fine arts. In the second place, there is the faithful copy, wrought out by the graver's tool on a substance from which numerous impressions can be taken: this is no longer an individual work, but one of a multitude; it is capable of being carried on simply by a clever use of tools in the hands of faithful copyists. Observation and imitation are needed, as well as a great degree of skill and taste in transferring the subject to the new material, but original ideas are not required: this, therefore, must of necessity be ranked as a useful art—useful, as widely diffusive of the pleasure conveyed by the fine arts; and likewise useful, as affording a field of remunerative labour to thousands of individuals who may be constitutionally unfitted for other employments.

But while engraving must thus take its place among the useful arts, yet it must not be denied that in order to have the true spirit of the subject conveyed to an engraving, something more than ordinary skill and successful imitation is demanded of the engraver. It has been well remarked by a tasteful writer,[1] that "the engraver is to the painter, what the translator is to the author. As it is impossible to give a spirited translation of a work of genius without a portion of the author's fire, so it is essential to a good engraver that he should feel and understand the character of the original, and be initiated into the art of drawing, that his copy may at once be correct and spirited." But for this gift displayed in the works of many of our best engravers, we should still fail of the enjoyment the art is calculated to produce in the faithful rendering of the pictures of the first masters, and the multiplying of such instructive specimens in our various homes.

The art of engraving is of extreme antiquity. If it cannot with any certainty be traced to antediluvian times in the case of Tubal-cain, the son of Lamech, who is spoken of as "an artificer in brass and iron" yet there are distinct traces of it in the patriarchal age, for carved images were found in the family of Abraham, and these, if we may judge by analogy with the most ancient remains of carving extant, were merely rude outlines on a flat surface, and therefore bore a strong resemblance to engraving. During the sojourn of the Israelites in Egypt they probably exercised this art after the Egyptian manner, which consisted of hieroglyphical figures, cut in outline on metal and stone. But during their wanderings in the desert, two men (Bezaleel and Aholiab) were specially set apart to "devise curious works in gold, silver, and brass, and in the cutting of stones to set them, and in carving of wood," for the service of the tabernacle; and of them it is declared that God "filled them with wisdom of heart to work all manner of work of the engraver." Exod. xxxv. 35.

The rude methods of Egypt are supposed to have been adopted by the Phœnicians, and thus to have been conveyed to Greece, where, in Homer's time, the art of engraving had considerably advanced. One of its earliest uses in that civilized nation was in the delineation of maps on metal plates. Specimens of the art as practised in Etruria are thought to be of a very remote antiquity, and are quite capable of being printed from, as has been proved by actual experiment. But the idea of filling in these rude outlines with ink, and taking impressions from them, was reserved to later times. Thus, the ancients just missed a discovery which now forms the principal element of our progress. This is the more remarkable when we remember that they knew how to take impressions of seals and stamps in wax, clay, and other soft bodies, and that they seem to have had stamps with separate letters engraved upon them.

The art of engraving comprises three great divisions, for which appropriate technical terms have been found by referring to the Greek language. Copper-plate engraving is named *Chalcography*, from the Greek words signifying *copper*, and *I inscribe;* wood-engraving, *Xylography*, from *wood*, and *I inscribe*; engraving on stone, *Lithography*, from *a stone*, and *I inscribe*.

The first of these, or the art of engraving on copper, and taking impressions from the engraved plates, is ascribed to a native of Florence, named Finiguerra, who flourished in the fifteenth century. He was a skilful workman in a species of handicraft then largely practised, namely, the engraving of church ornaments and other articles, and filling the engraved parts with a black composition of silver and lead. This was called working *in niello*, and had a good effect, as may be seen by remaining specimens. It is said that Finiguerra having on one occasion cast some melted sulphur on his engraving, to try its effect previously to putting on the black composition, observed, on removing the sulphur, that some dust and charcoal which had gathered in the hollows gave an impression of what he had engraven. On this he tried the effect of moistened paper, pressed down on the engraving with a roller, and met with complete success. Other goldsmiths and engravers followed in the steps of Finiguerra, and this important discovery soon became widely diffused. Throughout the sixteenth century improvements in this art were numerous in Italy, and the skill of Marc Antonio Raimondi, and the students of his school, raised the fame of the Italian engravers to a high pitch.

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[1] Allan Cunningham.

Meanwhile Germany was making rapid progress in the same art, first practised in that country by Martin Schongauer, and carried to eminence by Albert Durer and his followers. The artists of the Flemish and Dutch schools, together with the skilful engravers of France, also contributed to spread throughout Europe the triumphs of this interesting branch of knowledge.

The art of engraving was early known in England. Printing was discovered during the first half of the fifteenth century, and engraving quickly followed, as is proved by Caxton's "Golden Legend," printed in 1483, and ornamented with numerous woodcuts. Copper-plate engravings appeared in Vesalius's "Anatomy," printed in England, in Latin, in 1545. These were the work of Thomas Geminus, or Geminie, the first English engraver of whom we have any distinct record. A translation of the work by Udall, dedicated to Edward VI., contained in the preface the following passage: "Accepte, jentill reader, this Tractise of Anatomie, thankfully interpreting the labours of Thomas Gemini the workman. He that with his great charge, watch, and travayle, hath set out these figures in pourtrature, will most willingly be amended, or better perfected of his own workmanship if admonished." The first maps of English counties were engraved by Christopher Saxton in 1579.

In the reign of Charles I. an engraver-royal (Voerst, a native of Holland) was appointed, and the art received much encouragement from the king and the Earl of Arundel. The celebrated Vandyke assisted its progress by his vigorous and expressive etchings; various improvements were made; Prince Rupert discovered *mezzotinto*, and for a brief period engraving flourished greatly; but the bad taste and dissolute manners of the succeeding reign checked its progress, and had the worst effect on the art. Its subsequent revival and brilliant success in the hands of Hogarth and his cotemporaries, and its high eminence at the present day, present too extensive a field to be traversed here. Sufficient that we describe some of the processes of this interesting art as now practised.

Supposing a copper-plate engraving to be begun and carried on without the aid of etching, it is as follows: A plate of copper is first prepared, smooth and free from all imperfections, very hard and highly polished. On this plate the outlines of the landscape or subject to be engraved must be accurately traced. To this end the copper-plate is first heated in an oven till it attains a sufficient uniform heat to melt white wax, a piece of which is rubbed over it, and allowed to spread in a thin layer till the whole surface is equally covered; after which it is left in a horizontal position till the wax and plate are cold. In the interval a careful tracing of the original design is made with a black-lead pencil on thin tracing paper, and this is afterwards laid down upon the waxed surface of the plate, with the lead lines in contact with it. The tracing being secured in this position, heavy pressure is applied, the effect of which is to transfer the lead lines from the paper to the wax. The engraver now takes a fine steel point, and (the tracing-paper being removed) goes over the subject lightly, so as just to penetrate the wax and touch the copper. By this means a perfect and delicate outline is drawn upon the plate, and when the wax is melted off, the subject is ready to be proceeded with and finished off, according to the skill and manual dexterity of the engraver. These are not within the powers of description; but we may briefly state that the principal instrument employed is the *graver* or *burin*, made of steel, and cutting at an acute-angled pyramidal point. The instrument is held in the hand at a small inclination to the plane of the copper, and is pushed forward in the direction required, to cut the lines on the plate. See Fig. 863. Should the lines be cut too deeply, a smooth tool, about three inches long, called a *burnisher*, is employed to soften them down, and also to burnish out scratches in the copper. But the graver, in ploughing furrows in the surface of the copper, raises corresponding ridges or burrs; these have to be scraped off by another tool, about six inches long, called a *scraper*, also of steel, and having three sharp edges. A woollen rubber is also commonly used, with a little olive oil, to clear the face of the plate, to show the progress of the work, and to rub off the burr. Many engravers also use a leather bag, filled with sand, as a cushion to support the plate during the progress of the work. When a series of parallel lines are wanted, in architectural subjects, or for skies, manual labour can be dispensed with, and a ruling machine substituted, which works with most complete effect. The above method was the ordinary one in former times, and is still continued in the engraving of letters, silver plate, &c.; but since the discovery of etching it has almost universally given place to that freer and more expeditious process.

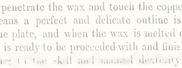


Fig. 863.

Besides engraving, properly so called, there are several varieties known, as *etching*, *mezzotinto*, *aquatinta*, &c.

Etching now forms a most important part of the engraver's art, for nearly all his productions are commenced, and to a considerable extent, are carried forward by its aid. It is the process of corroding with aquafortis the lines of a drawing, traced out with an etching needle on the copper-plate, over which has been previously placed what is called an *etching ground*, namely, a preparation of bees'-wax, Burgundy pitch, &c., incorporated over the fire, and capable of resisting the action of the aquafortis. The following composition forms a good etching ground:—two ounces of white wax, half-an-ounce of Burgundy pitch, half-an-ounce of black pitch, and two ounces of asphaltum. The ingredients, with the exception of the asphaltum, are put into a crucible and melted over a slow fire. The asphaltum meanwhile is reduced to a fine powder, and is stirred into the composition by degrees. When the substances are all intimately blended, the composition is poured into cold water, and worked into balls about the size of a walnut, which are tightly and smoothly tied up in small pieces of plain worn silk. When the plate is to be prepared for etching it must first be heated with an equal heat throughout, by holding it by means of a hand-vice over a stove, or in an oven. A bit of folded paper will save the plate from injury at the points where the vice presses. No more heat is required than is sufficient to melt the composition, or etching ground, which is now applied by rubbing one of the silken balls over the plate, the warmth of which causes the substance to ooze through the silk. The ground is then equalised by rubbing with a dauber. This is variously contrived, but a simple kind is made of lamb's wool, properly washed and dried, and then tied up in soft fine muslin in the shape of a flattened ball. Outside this must be smoothly stretched and tied a piece of black silk, not new or twilled, otherwise it will cause the surface to be unequal. When the daubing is completed, and the etching ground smoothly and equally distributed, the copper-plate is held, face downwards, over the flame of a wax candle, or of two or three candles tied together, until the whole surface of the etching ground is smoked to blackness. It is then ready to receive the design, which is first made in outline with a black-lead pencil on a piece of thin even paper, and then placed face downwards on the smoked surface. The whole is then passed through the roller-press used for printing copper-plates, which transfers an impression of the outline to the ground. After this the design is completed with the etching needles, a very fine point being used for the more distant and delicate parts, and a broader one for the nearer and bolder objects. These needles remove the wax composition or etching ground from the copper wherever they pass, and slightly scratch the surface of the plate, thus exposing it to the full action of the acid during the subsequent process of biting-in. To prepare for this, a border of wax half an inch high is put round the plate to form a trough for the acid. This is called *banking-wax*, and is made of bees'-wax, common pitch, Burgundy pitch, and sweet oil, melted in a crucible, and poured into cold water: when cold it is quite hard, but on immersion in warm water it becomes soft. The wax having been made to surround the copper-plate, and being sufficiently hardened, the next operation is to pour in nitrous acid, reduced with water to the proper strength, (usually about one part acid to four parts water,) which experience alone can teach. Its action on the copper is apparent in the rising of innumerable bubbles. When the acid has been on a sufficient time to corrode the fainter and more distant parts of the subject, it is to be poured off, the plate washed with water, and left to dry. These fainter parts are then to be varnished with a mixture of lamp-black and Venice turpentine, applied with a camel's-hair pencil, which stops the further action of the acid on those parts. Hence the mixture is called *stopping-ground*. When it is dry the acid is again poured on, and the action renewed on the bolder parts of the subject. This stopping-out and biting-in can be repeated as often as the nature of the subject or the taste of the engraver may suggest, so that many gradations of tint can be obtained. After this the waxen border is removed by heating the plate, and by a little further warming the etching ground can also be wiped off with a rag moistened with olive oil. The work is now complete, unless it be wished to finish it more highly with the graver. This is frequently done, for, as we have already noticed, almost every engraving at the present day is partly etched. Etching points or needles resemble common needles, fixed in handles four or five inches long. Some are, however, made of an oval form, in order to produce broader lines. What is called the *dry-point* is nothing more than the common etching needle brought to a very fine point, for the purpose of cutting or scratching the more delicate lines of skies, &c. The dry-point does not cut the copper clean out, but raises a slight ridge or burr, which is ordinarily removed with the scraper, but which may in some cases be left on with fine effect. This is the case with Rembrandt's etchings, in which the burr was left on till it wore away in printing. Early impressions of his etchings, in which this peculiarity is visible, are therefore much valued. Imitations of chalk and pencil drawings are sometimes produced by etching on soft ground, but this practice has been greatly superseded by that of lithography. Etching on steel is performed in the same way as on copper, the steel also yielding a greater number of good impressions. A species of etching is also employed in the representation of medals, a machine of peculiar construction being brought into operation. For etching on glass, a ground of bees'-wax is laid on, and the design is traced with the needle as before. Sulphuric acid is then poured on, and fluor spar sprinkled upon it, or fluoric acid may be at once used: this is allowed to remain four or five hours, and is then removed with oil of turpentine. Etched imitations of chalk drawings of the human figure, called engravings in *stipple*, have a very soft effect, but are inferior to engraving. In this variety the whole subject is executed in dots without strokes on the etching ground, and these dots are bitten-in by aquafortis. Again, these dots may be harmonized with a little hammer, in which case the work is called *opus mallei*. In the method known as *mezzo-tinto* a dark barb or ground is raised uniformly by means of a toothed tool, and the design being traced, the light parts are scraped off from the plate by fitting instruments, according to the effect required. In *aquatinta* the outline is first sketched, and then a sort of wash laid on with aquafortis upon the plate, producing the effect of Indian-ink drawings. Copper-plate engraving, therefore, in all its varieties, opens a wide field for the taste and industry of those who would perpetuate and multiply valuable works of art in the several styles best suited to their respective subjects.

Steel-engraving is performed in the same way as copper-plate engraving, with the exception of some slight modifications in the use of acids. The improved presses used in both kinds of engraving are due to Mr. Jacob Perkins, who may be said to have established steel-engraving by his invention of decarbonizing the plates, so as to make them fit to be engraven on, and also by his interesting method of multiplying impressions on steel-plates. Mr. Perkins's method of transfer-engraving originated in the transfer processes employed in engraving the copper cylinders used in calico-printing. The subject intended to be multiplied is first engraved either by hand or machinery, or the two may be combined, in the best style of art on a plate of soft steel; the plate is then hardened. A decarbonized steel cylinder is next rolled over the hardened plate by means of powerful machinery, until the engraved impression appears in relief, the hollow lines of the original being raised on the cylinder. The roller is then reconverted to the condition of ordinary steel, and hardened, after which it can be used for returning the impression to any number of decarbonized plates, each of which is of course an exact counterpart of the original. It is said that each of these plates when hardened would give 150,000 impressions without being materially worn. The original plate thus serves only to give one impression to the transfer roller, which in its turn is used to produce any number of plates. Should any accident happen to the transfer roller, another impression can easily be taken from the original plate.

In order to decarbonize the plates they are placed in a vertical position in cast-iron boxes not less than ¾ inch thick, and surrounded on all sides by a stratum of iron-filings not less than ½ inch thick; the boxes are then placed in a furnace, and after being heated are cooled very slowly by stopping up all the air passages, and covering the boxes with cinders to the depth of 6 or 7 inches. The decarbonized plates are reconverted into steel by enclosing them in boxes as above, and surrounding them with fine charcoal made from leather; they are left at the proper heat for from 3 to 5 hours, and on being taken out are immediately plunged in a vertical position into cold water.

Wood-engraving (*Xylography*) is said to have had its origin in China, the birth-place of many other valuable inventions, and to have been due to the peculiar structure of the Chinese language, in the writing of which a separate symbol is used for each idea, and words are not made up, as with us, by a combination of letters. The number of these symbols or characters is therefore so vast that it would be almost impossible to print their books with movable types. Their method of printing is therefore as follows: the work to be printed is carefully transcribed upon transparent paper, only one side of which is written on. The sheets are then glued down upon wooden tablets, and all the wood is cut away except that covered by the lines of the writing. From these raised wooden lines impressions are taken. This practice is of ancient date in China, and some of those who have bestowed research on the matter are inclined to fix it about A.D. 950. As far as it is now possible to trace the introduction of wood-engraving into Europe, it would appear that the Venetians, in their commerce with the Chinese, early learned this art, and practised it before it was known to other European nations. But the art was eagerly acquired by Germany and the Low Countries, and in 1433, or thereabouts, they carried on a considerable commerce in playing-cards and prints of saints. At that time the engraver on wood was called *Form-schneider*, or figure-cutter, a term still in use. The little prints of saints were rudely executed, and had a great sale among the common people. In Germany they were called *Heiligen*, or *Helgen*; in France, *Images*. They were at first sold separately, and thus were soon dispersed and lost; but after a time they were pasted into religious books for the sake of preserving them, and thus probably originated the custom of illustrating books with engravings. From that time the art made decided progress. Block-books, as they are called, made their appearance. These were books in which the productions of the wood-engraver were simply collected in the form of volumes, some of which are still extant. One of the earliest, called the *Biblia Pauperum*, or Bible of the Poor, consists of 40 leaves, small folio, printed from the same number of engraved blocks of wood, on one side of the paper only. These prints are placed two by two, facing each other, so that by pasting their backs the book has the appearance of being printed in the usual way on both sides. The use of printed characters in books is closely connected with the origin of wood-engraving, but the exact time of the invention is a disputed point. One of the most generally received accounts of this discovery is thus given by an old German chronicler:—

"At this time (about 1450), in the city of Mentz, on the Rhine, in Germany, and not in Italy as some have erroneously written, that wonderful and then unheard-of art of printing and charactering books was invented and devised by John Gutenberger, citizen of Mentz, who, having expended most of his property in the invention of this art, on account of the difficulties which he experienced on all sides, was about to abandon it altogether; when by the advice and through the means of John Fust, likewise a citizen of Mentz, he succeeded in bringing it to perfection. At first they formed or engraved the characters or letters in written order on blocks of wood, and in this manner they printed the vocabulary called a 'Catholicon.' But with these forms or blocks they could print nothing else, because the characters could not be transposed in these tablets, but were engraved thereon as we have said. To this invention succeeded a more subtle one, for they found out the means of cutting the forms of all the letters of the alphabet, which they called matrices, from which again they cast characters of copper or tin of sufficient hardness to resist the necessary pressure, which they had before engraved by hand." In this latter process the original inventors were greatly aided by Peter Schoeffer, son-in-law to Fust, who shares with the other two in the honours accorded to the worthy citizens of Mentz. An early and celebrated result of the union of typography and wood-engraving was a Psalter printed on vellum by Fust and Schoeffer, at the end of which there is a congratulatory paragraph on the discovery of the art of printing. The large initial letters of this Psalter are beautifully executed and printed in two colours.

The artists of Italy competed successfully with those of Germany, in the prosecution of this interesting art, but attention was recalled to German art by the engravings of Albert Durer and his cotemporaries, during whose time wood-cutting was in high estimation. At the close of the 16th century this art had greatly declined in Germany, but was better understood in France and England than at any previous period. Yet it was reserved to the 18th century to give a powerful impulse to the art in Britain. This was done by Thomas Bewick, who showed, in his "British Birds," a most skilful and effective adaptation of the means his art then afforded of faithfully representing nature. He was undoubtedly the instrument of a great revival in wood-engraving, and led the way in that career of success which has since distinguished the wood-engravers of this country.

The processes connected with wood-engraving chiefly differ from those of copper and steel engraving with respect to the different nature of the material employed. Box-wood is the only kind that can be successfully employed in wood-engraving. American or Turkey box is of large size, but is inferior in quality to our English wood. It should be of a clear yellow colour, as equal as possible over the whole surface, without spots or variations of tint, which mark inequality of growth and consequently of hardness, and which are sometimes quite evident in the impressions taken from such blocks, the whiter portions being softer and more absorbent of ink, and retaining it more tenaciously. The natural hardness and toughness of box, with the poisonous nature of its juices, are of great importance in preserving blocks from the attacks of insects, to which apple, pear, and beech-wood, sometimes used for the purposes of engraving, are naturally liable. But box-wood requires to be well-seasoned, otherwise it is liable to warp and bend. If a block of unseasoned wood be allowed to lie flat for a week or two, it is almost sure to bend upwards at the edges. Blocks of wood, therefore, should always be placed on their side edges when laid by for future use, and in the process of engraving they should be turned over on their faces, in the intervals of the work, or some degree of curvature may be given to them by the warmth of the engraver's hand. When a block becomes slightly concave, and the circumstance is not noticed by the pressman previous to taking an impression, the block frequently splits. Blocks of wood, when [illegible] and polished, are prepared for drawing on, by simply rubbing the polished surface with bath brick in very fine powder slightly mixed with water. When this thin coating is dry it is removed by rubbing the block with the palm of the hand: its only use is to make the surface less slippery. Some artists, previous to beginning their drawing, wash over the surface of the block with flake-white and gum-water, but if the white ground be too evident the effect is confusing to an engraver in the progress of his work, the parts cut being of the natural colour, while the uncut parts are white. "The less that is done to alter the natural colour of the wood," say the best engravers, "the better." Flake-white is also apt to mix with the ink in taking a first proof, and to fill up the finer parts of the cut.

As box-wood is, notwithstanding its hard and compact nature, very much softer than copper and steel, and is, moreover, less equal in density throughout, so the graving tools must be guided in a different manner, and a check must be put on the force with which they are ordinarily sent forward by the palm of the hand. There are four descriptions of cutting-tools used in wood-engraving; and numerous specimens of each, differing in size and degrees of fineness, are kept at hand. Of the four kinds of tools, the first is the graver, differing little from that of the copper-plate engraver, but adapted to the purposes of wood-cutting by having the point ground to a peculiar form by rubbing on a Turkey stone. Eight or nine gravers of different sizes are generally required, commencing with a very fine one, called the outline tool. The upper part A, Fig. 864, is the back, the lower part D is technically called the belly; B is the face of the tool; C, its point. The latter is so extremely fine that the line is scarcely perceptible when the cut is printed; the object being with this tool merely to form a termination or boundary to other series of lines. This tool, in common with others, is fixed in a convenient handle, which, as it is received from the turners, is perfectly circular at the end; but part of this rounded end is cut off after the blade is inserted, in order to accommodate the tool to the flat surface of the block, and also to insure its being ready to the hand in the right position for use when laid aside and then taken up again. Eight or nine gravers, Fig. 865, are required, beginning with the outline tool, and increasing in size and breadth. The engraver also adapts them to his particular purpose, either by making them finer, or by grinding them down to greater breadth, and rounding them slightly at the points. The lower dotted line in

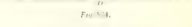


Fig. 864.

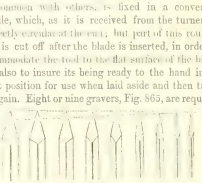


Fig 865. GRAVING TOOLS.

Fig. 865 shows the extent to which the points are usually ground down. Gravers are used for nearly every description of wood-cutting, occasionally, not even excepting "tinting," the technical term applied to cutting series of parallel lines, which, when engraved, form an even and uniform tint. For this process, however, there is a distinct set of tools, Fig. 866, thinner, and ground to a much more acute angle at the face. These tools, though thin, ought to be sufficiently strong at the back to prevent their bending when used: their

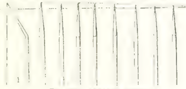


Fig. [illegible]

faces, as well as those of the gravers, should also be rather long than short, for they then cut with much greater clearness, and the shaving of wood turns gently over towards the hand, as shown in Fig. 867;

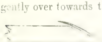


Fig. 867.

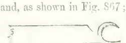


Fig. 868.

whereas, when the graver is too obtuse, the shaving, instead of turning aside, coils over before the point of the tool, as in Fig. 868, and hides the pencil-line which the engraver is following. A, Fig. 869, is an

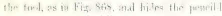


Fig. 869.

example of an obtuse form of tool: this may be converted into an acute tool by grinding down the portion shown by the dotted lines in B. In addition to gravers and tint-tools there are gouges of different sizes, Fig.

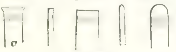


Fig. 870.

870, for scooping out the wood towards the centre of the block, and flat tools, or chisels, for cutting it away towards the edges. A form of flat tool, marked C, is to be avoided, as the projecting corners are apt to cut under a line, and give much trouble in plugging, or inserting new wood, on which to replace it.

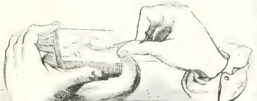
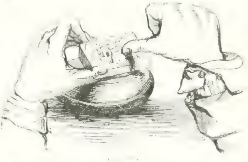


Fig. 872.

[illegible] graver [illegible] when the material is wood, to that employed in copper and steel engraving. In the latter case, the forefinger is extended on the back of the tool, so as to press the point into the plate. (See Fig. 863.) In wood-cutting this is not necessary, but, on the contrary, the force of the hand has to be checked by the thumb, which in small subjects is rested against the side of the block, allowing the blade to move freely, but ever ready to check it in case of a slip. See Fig. 871. In larger subjects, the thumb accomplishes the same ends by resting on the surface of the block. See Fig. 872.



Engraving requires delicate and skilful workmanship, and makes large demands on the eyesight as well as on the dexterity of hand of those who practise it. Some parts of the work are generally supposed to require the use of magnifying glasses, and much of it must necessarily be accomplished by lamp-light. The most experienced engravers, however, are slow to recommend the use of glasses to those who can possibly do without their assistance. Young persons commencing the art of wood-cutting seem to imagine that a magnifying glass must of necessity form part of their apparatus. The sort of glass employed is similar to that of watch-makers, and consists of a single lens fitted into a short tube, and rather wider at the part applied to the eye. Such aid should only be sought when sight begins to fail; and even then the glass should at first be of low magnifying power. Various means are employed to protect the eyes from the light, and the face from the heat, of the lamp. One of these consists in the use of a large glass globe filled with water, which is interposed between the lamp and the engraver's block. By the use of these globes one lamp is found sufficient for three or four persons, and each person has a clear and cool light to work by. In damp or frosty weather, the breath of the engraver is apt to injure his work, unless some contrivance be adopted to prevent its playing on the surface of the block. This is usually found in a screen of thin pasteboard or stiff paper, temporarily tied across the mouth and nostrils in such weather. The eyes have their own protection, from a shade which most wood-engravers wear, not only to guard the sight, but also to concentrate the view on the work in hand. Such shades are, however, very objectionable, as they confine hot air close to the eyes, which require for healthy action the free circulation of fresh air.

The pupil in wood-engraving commences with the cutting of parallel lines or bars, straight and [illegible] and then proceeds to simple forms in outline, without any shading that is expressed by cross-lines. Such shading is necessarily difficult in a material where all the parts intended to be light have to be cut away, and the dark lines alone remain standing; and consequently in cross-shading the interstices have to be carefully hollowed out, without injury to the lines. Complicated subjects should be long deferred, and never attempted till decided success has attended the simpler efforts.

Lithography, or engraving on stone, is a modern invention, ascribed to a musician named Senefelder, connected with the theatre at Munich, about the year 1800. The term engraving is not truly applicable to the process, as usually carried on; but in Germany a great deal of actual engraving on stone with the burin is practised. The results of this method, however, are so greatly inferior to those of copper-plate engraving, that it is not likely ever to come into general use. The art of taking impressions from drawings made on stone depends on the readiness with which calcareous stone imbibes water, its great disposition to adhere to resinous or oily substances, and the disposition those substances have to combine, and to repel water or any substance moistened with water. Drawings made on a polished surface of calcareous stone with a resinous or oily substance adhere strongly to the stone, and are not at all affected by water poured over it, and which the other parts imbibe readily. But if a resinous or oily body be then passed over the stone, it will adhere strongly to the drawing, and not to the watery parts of the stone.

The drawings, therefore, in lithography, are made with ink and chalk of a soapy nature. The ingredients of the former are tallow-soap, pure white wax, lamp-black, and a small quantity of tallow, all boiled together, and when cool, dissolved in distilled water. The ingredients for the chalk are the same, with a small quantity of potash added during the boiling. After the drawing on the stone is perfectly dry, a very weak solution of sulphuric acid is poured over it, which takes up the alkali from the ink or chalk, and leaves an insoluble substance behind it, while it lowers in a slight degree the surface of the stone not drawn upon, and prepares it for the free absorption of water. Weak gum-water is next applied, to close the pores of the stone, and keep it moist. The stone is then washed with water, and the printing-ink applied in the ordinary way. It then passes through the press; the washing with water and daubing with ink being repeated after every impression. The impressions may be multiplied to a great extent, without any marked failure in the effect. As many as 70,000 copies or prints have been taken from one stone, the last being nearly as good as the first. The work can also be performed with great expedition and economy. Drawings made with the chemical ink on paper prepared with a solution of sise or gum tragacanth can be transferred to the stone, by being merely laid thereon and passed through the press, when the subsequent processes can be carried on, as already described. Copper-plate and steel engravings can be transferred to stone, and worked by power presses, thus lessening the expense, and affording a convenient mode of multiplying maps which may be required in large quantities. [See APPENDIX.]

ENVELOPE-FOLDING MACHINE. Among the machines exhibited in motion in the Great Exhibition, Messrs. De la Rue and Company's envelope-folding machine was always surrounded by a crowd of interested spectators; and it is worthy of the admiration which it has excited; for whether we regard the rapidity and precision with which it does its work (folding an envelope every second), or study the anatomy of its structure, we have a striking illustration of the proposition, that whatever merely mechanical operation is performed well by human hands, can be effected much better and far more quickly by a self-acting machine. Through the kindness of the inventors, we are able to lay before our readers a sufficiently minute description of this machine.

As the various motions of this machine are produced by means of cams, it will be necessary to the due understanding of the subject to describe the nature of a cam, and the method by which it is produced.

A Cam is a contrivance in which sliding contact is employed to communicate a velocity ratio, either constant or varying, between two pieces of mechanism. The extent of motion of one of these pieces must be limited, that of the other may or may not be continuous. Thus for example, if one of them be required to move in a short rectilinear path in the manner of a rack or sliding bar, an axis revolving indefinitely in one direction, or with a defined to and fro rotation in both directions, may, by means of a cam, be made to give motion to this bar or rack. If the relation between the speed of movement of the bar and that of the axis be uniform, then the velocity ratio is said to be *constant*. If, however, the speed of the bar does not, in the successive periods of its motion, bear any uniform relation to the velocity of the axis, then the velocity ratio of the two pieces is said to be *varying*.

Let A, Fig. 873, be the centre of motion of a plate, to which an alternating movement of rotation can be given. In this plate a slit *a b* is pierced, having parallel sides, so as to embrace and nearly fit a pin *m*, carried by a bar C D fitted between guides, so as to be capable of sliding in the direction of its length. While the plate revolves in the direction of the arrow, the inner side of the slit presses against the pin and moves it further from the centre A; but when the plate revolves in the opposite direction the outer edge of the slit acts against the pin, and moves it in towards the centre. If the linear velocity of translation of the bar be required to be exactly

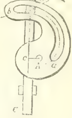


Fig. 873.

equal to the circular velocity of a point c of the plate, then the curve $a\ b$ must be an involute of the circle whose radius is A c. So for other constant velocity ratios, curves can be found which shall fulfil the required conditions.

If the sliding movement of the bar be required to continue during several revolutions of the axis A, the curve $a\ b$ becomes converted into a spiral or *plane screw*, Fig. 874. Were the rotatory motion of the axis indefinite and in one direction only, the to and fro sliding motion of the bar might be effected by continuing the slit $a\ b$, Fig. 873, in a curve exactly like the first, but inverted in position, so that the summits of the two slits point at b, and their inner ends at a. It is obvious that in such a case the slit must not be carried quite through the plate, but must form a groove in its face only, as in A, Fig. 875.

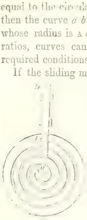


Fig. 874.

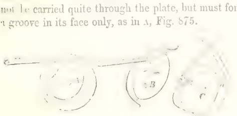


Fig. 875.

Now suppose that the velocity ratio of the two pieces is to vary, so that when a series of points, 1, 2, 3, 4, 5, Fig. 876, in the circumference of the circle c 3, 5, shall have reached in order the point c, the pin in the sliding bar shall be moved into the corresponding positions I, II, III, IV, V. To each of the position points in the circumference of the circle draw tangents, and from the centre A draw circular arcs through the given positions, I, II, III, IV, &c. intersecting the respective tangents, as at $a\ b\ c\ d\ e$. Then a curve drawn through this series of points $a\ b\ c$ will be the curve required; for it is clear that if any point (as 3) of the circle be moved to c, the corresponding point c of the curve will be in the position III, and therefore the pin acted on by this curve will be moved as required: and so for any other pair of positions.

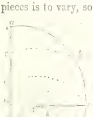


Fig. 876.

When the grooved plate is used, the line thus traced is the centre of the groove, from which the half thickness of the pin must be set off on both sides to give the width of the groove required. But it is obvious, that if the pin be, by the pressure of a spring, or weight, or by other contrivance, made to bear steadily upon the edge of the plate $a\ b\ c\ d\ e$, Fig. 876, the required movement may be obtained. Such a plate acting on an oscillating arm (which is called a *follower*) is shown in Fig. 877. The follower will obviously make one double oscillation up and down during each revolution of the axis.

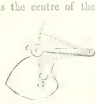


Fig. 877.

Such a cam has its most simple form when no sudden change of velocity is required in the follower, and one complete double oscillation is to be made for each revolution of the axis. The cam then becomes an eccentric circle, as at C, Fig. 878. Here a is the eccentric centre of motion, b the centre of the cam, $a\ c$ the direction of the motion in the follower, which is a roller, whose centre is c. Then $b\ c$ is constant, and the motion given to the follower is the same as if a link $b\ c$ and crank $a\ b$ were employed. This form may be modified, as in Fig. 879, by attaching a pin c to an eccentric disc revolving about a centre a. This pin working in a slotted arm, communicates to it an oscillating motion about its centre b.

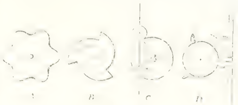


Fig. 878.

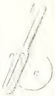


Fig. 879.

When the bar or follower is to make a number of oscillations during each rotation of the axis, the cam may assume the form of A, Fig. 878; or if a series of lifts, each with a sudden return of the follower, be required, the outline of the plate may be like B, Fig. 878. When these lifts are communicated (as to a set of stampers) with intervals of rest between them, the cam becomes a disc bearing projecting teeth or cogs, as at D, Fig. 878. Such teeth or cogs are then called *wipers* or *tappets*.

When the use of a spring or weight to bring back the follower is inconvenient, the grooved plate already described (A, Fig. 875,) may be employed. If the cam revolve always in the same direction, the outside of the curve is required during that portion of the revolution only in which the follower approaches the centre. Its place may then be supplied by a bar or guide fixed to the cam, as at B, Fig. 875. Or the follower may have two arms, as in C, Fig. 875, resting on two distinct cams, placed one behind the other on the same axis, so that when the edge of one cam is retiring, that of the other is advancing. Care must be taken that the distance $m\ n$ between the points of contact of the follower-arms shall be always the same. It is obvious, that by varying the form of the curve for the groove or circumference of the plate, the motion of the follower at the several phases of its oscillation may be regulated at pleasure.[1]

These few remarks may be appropriately wound up with a description of the method by which the main cam of the envelope-folding machine was formed. c, Fig. 880, is the centre of the cam, and c′ the centre of the lever or follower. The extent of motion of this lever is first determined by means of the arc *a a′*, which if prolonged would reach the centre c. The fraction of the revolution of the wheel, *i.e.* the time occupied in the motion of the lever, is also predetermined, and marked out by means of the arc *r r′*.

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[1] Figs. 873 to 879 are from Professor Willis's "Principles of Mechanism." London. 1841.

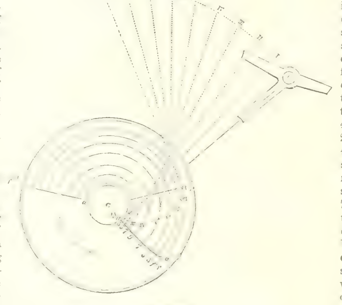


Fig. 880

With the radius c c′ draw an arc c′ c″, and from c′ set off the portion c IX, corresponding to the angle comprised between the radii *r r′*. Divide this into any odd number of parts, nine for example, numbered in a direction opposite to that of the motion of the cam, I, II, III, &c. Now by the laws of mechanics, a falling body moves in successive intervals of time through spaces corresponding to the odd numbers, 1, 3, 5, 7, &c., and as it is of advantage to give equal impulses to the machine, the same law is followed in the extent of motion given by the cam to the lever; but if this law were to operate until the end of the motion, a considerable shock would be given to the machine, since the body being set in motion would be moving at its greatest velocity by the time it had completed one revolution. It is therefore arranged that this law shall be maintained up to a certain point, or until the centre of the motion is arrived at, after which, the motion is continued with a velocity constantly decreasing in the same ratio as it before increased. For example, in the nine periods previously determined on,

Period I.	a space is moved through equal to	1
II.	,, ,,	3
III.	,, ,,	5
IV.	,, ,,	7
V.	,, ,,	9
	or as the square of the times	25
VI.	a space is moved through equal to	7
VII.	,, ,,	5
VIII.	,, ,,	3
IX.	,, ,,	1
	or in the inverse ratio of the squares of the times	41

We therefore divide the arc *a a′*, described by the lever c′ *a* during its predetermined motion, into 41 spaces, and beginning at *a* describe from the centre c a circular arc, passing through the zero or starting point of these divisions. In the same way, successive segments of circles are drawn from the centre c, at such distances as to pass through the 1st, 4th, 9th, 16th, 25th, 32d, 37th, 40th, 41st, divisions from *a* (corresponding to the spaces, 1, 3, 5, 7, 9, 7, 5, 3, 1), and intersecting the radii *a r* and *a″ r‴*. With the radius *a* c′, placed successively at the intervals I, II, III, IV, &c. on the arc c′ c″, intersect the arcs I, II, III, IV, &c. A curved line *a* to IX. drawn through these various intersections, is the centre line of one face of the cam. The lever might be made to return immediately to its former position, or to any intermediate position, but in the cam about to be described it is intended to remain for a certain period at rest; therefore, the centre line of that portion of the cam which is intended to keep the lever at rest, must evidently be a portion of a circle described from the centre c, and marked IX to *s*. The opposite face of the cam *s a″* is set out in precisely the same manner as the portion *a* IX, but it does not follow that it has the same form, because the elements may be different. The portion *a a′* being a period of rest is likewise concentric to the centre c. From this centre line the half diameter of the roller or stud to be used on the follower of the cam is set off on both sides, so as to mark out a broad path having its two boundaries equi-distant at all points from the centre line *a r r′ a″*. Within this path the roller travels in the same way as the pin in the grooved plate already described. A roller is used simply to diminish friction, and to prevent the abrasion and consequent change of form of the curved path.

In this machine all the cams are double; that is, the truck or roller attached to each of the levers is controlled in its motion by two surfaces, and not, as is often the case, by one surface, against which it is pressed by a spring. This latter method is objectionable on account of its absorbing a great amount of power; for unless the spring be strong enough to keep the truck in close contact, it is apt to fly off and produce shocks to the machinery, especially if the steam engine or driving power should happen to be slightly accelerated in speed.

Each cam is formed by projection on a circular disc, the eccentricity being counterbalanced by a projecting counterweight, cast opposite to its centre of gravity.

Each lever is also constructed so as to be balanced when swung at its centre. In the case of the two levers 4 and 5 of the plunger 6, Fig. 884, their construction only admits of their being balanced by the counterweights 4″, 4‴.

The principle of the cam being clearly understood, we next proceed to describe the various parts of the folding machine in the order of their work.

The functions of this machine are, to fold envelopes previously cut into the proper shape, and to secure the folds thus made by means of gum. The machine is fed with blank envelopes by a boy, at the rate of about one per second, this being the rate at which the principal cam revolves. The seal stamp is embossed on each blank, and the gum immediately under the seal is applied before the blanks are brought to the folding machine. This machine might be so arranged as to stamp the seal and feed itself; but in order to stamp efficiently, the parts must be made considerably stronger than they are in this machine, and it seldom happens that a sufficient number of envelopes are required from one seal to render such an adaptation economical. Moreover, every additional motion introduced must retard the progress of a machine; so that in this instance it is found more advantageous to engage the services of a separate machine. Then as regards feeding, a self-supplying apparatus would not in this case be of great advantage, because as some one must be present to superintend the machine, it is better that he be employed than remain idly looking on, for in such case his attention is apt to flag, and by allowing badly folded or broken envelopes to get into the machine much mischief may be done. Some idea of the precision with which this folding machine works may be gathered from the fact, that on an average there is not more than 1 envelope in 2,000 badly folded, and these generally arise from defects in the paper.

The blank envelopes, or *lozenges* as they are called, are cut out 250 at a time with great rapidity and precision, by means of an instrument identical in its action with a common gun-punch. E and F, Fig. 881, show two forms of lozenges, and may also be taken to represent the steel cutting edge of the punch. In the plain lozenge form E there is little or no waste of paper in the cutting out; but in the fancy envelopes (which are really less elegant in form than the plain lozenge) the waste is often considerable. Thus it will be evident, that there must be a greater waste in cutting out F, than in E. The waste paper is returned to the paper-maker to be made into pulp.

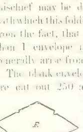


Fig. 881.

The blanks are next stamped with a seal at the embossing-press, [see EMBOSSING-PRESS,] and the seal flap is also gummed by hand. The lozenges thus prepared are then handed to the feeder [illegible], who places them one at a time on a small table T, seen best in Figs. 882 and 883, in such a manner that the angles fall within the stops *g g g g*, which stops also form the bearings of the triangular folders 5 5′ 5 5′. As soon as the envelope is placed on this table, the compound box or plunger 5, Figs. 884, 886, 887, is brought down by the cam 3 upon the table T, and this plunger descending with the table into the recess formed by the four ends of the folders 5′, creases the envelope and converts it into a rectangular form, the four triangular flaps standing up in a vertical position. The ends of the plunger being moved by [illegible] of the cam 3, shown by the dotted lines in Fig. 884, rise up so as to leave room for the two end folders 5 5′ to turn over, not simultaneously but one slightly in advance of the other, Fig. 885, so that one of the end flaps of the envelope may overlay the other. These two triangular folders are moved by the cams 6 and 7, in the order of the numbering. But before the other two flaps are turned over, it is necessary that gum be applied in the exact spot, in order to cause the points of the four triangular flaps to adhere. The gumming apparatus is seen separately in Figs. 888 and 889, the gummer being marked 10 in the other figures. After the two end flaps are turned down, this gumming apparatus is brought forward by the cam 11, and paints on the two end flaps a speck of gum imparted to it by an endless blanket. During the whole of these operations, the sides of the plunger 5, which had remained down so as to prevent the envelope from being disturbed, are now moved upwards by the cam 5, seen best in Fig. 884, and remain up until the commencement of the folding of another envelope, the two end folders remaining down to secure the envelope, and the gumming apparatus retreating. The two triangular side folders are now turned over by means of the two cams 8 and 9, one having a little the precedence of the other. The four folders then open simultaneously, leaving the envelope complete; but as the flaps of the envelope would, from the elasticity of the paper, be liable to spring open, there is a contrivance for keeping them pressed down; for which purpose, the apparatus which removes each envelope as soon as it is folded also places it in a pile immediately under the one last folded.

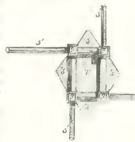


Fig. 882.

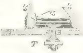


Fig. 883.

The taking off and piling apparatus consists of a slide 12, hinged at 12′, capable of rising and falling, and of a saddle 13′, carrying the fingers 13″, seen best in Figs. 886 and 887. The saddle moves in a hor-

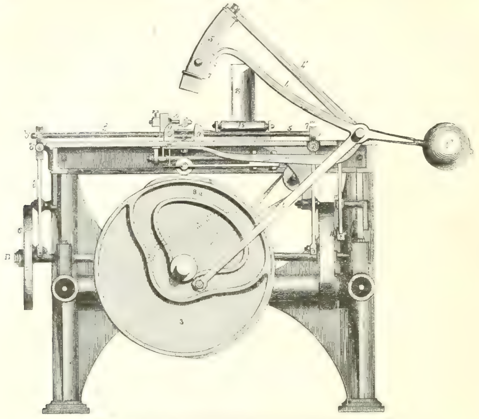


Fig. 884. SECTION OF FOLDING-MACHINE THROUGH THE LINE A B IN FIG. 887.

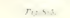
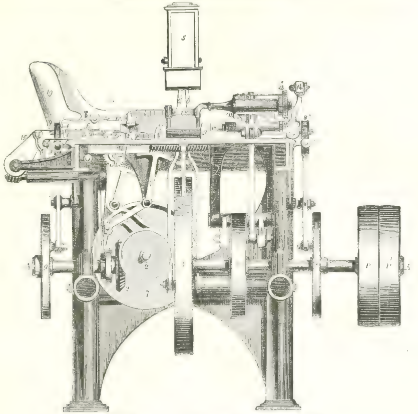


Fig. 885.

zontal direction on the slide 12. The points of the fingers move by a combination of these two motions, the vertical and the horizontal, in the line shown in Fig. 885, and in the direction of the arrows. After the envelope is folded, the fingers 15' are brought down into the recess formed by the axes of the folders 5', by means of the double cam 13, Fig. 887, one side of which is appropriated to the vertical motion of the slide, and the other to the horizontal motion of the saddle. When by these motions the fingers are brought into contact with the envelope, they are raised up, and at the same time the table T is made to rise with them, by means of a projection on the rim of the cam 3, Fig. 884, in such a manner as to keep the envelope firmly pressed against the fingers. The next motion of the fingers is the horizontal one; they are moved along the springing table 15, carrying the envelope with them, adhesion being promoted by tipping the points of the fingers with caoutchouc. As soon as the envelope reaches its destination under the pile, the slide is lifted by means of the cam 13, by which means the fingers are disengaged from the envelope, and they remain at rest until the next envelope is folded. The envelopes thus removed from the table are knocked over by means of a small beater 16, moved by a pin on the slide 12 on to an endless blanket 17, and pass under a small roller 18, which serves to compress the folds of the envelopes [illegible] closely together. The envelopes then rise in a pile in the three-sided trough 19, from which they are removed at intervals by an attendant.

On reference to Figs. 884, 886, 887, it will be seen that a series of racks 6″ 7″ 8″ 9″, serve to communicate motion from the levers 6′ 7′ 8′ 9′ to the wheels 6‴ 7‴ 8‴ 9‴, affixed to the folder axes 5 5 5 5. The object of this is to allow of the transmission of motion to the folding apparatus for envelopes of various sizes. The levers and racks retain their position, the folder axes being adjusted either at a greater or a less distance from the centre of the machine, in case a larger or a smaller envelope be required to be folded. Were it not for this provision, the cams and levers would have to be reconstructed for every variation in the size of the envelope, or, in other words, a new machine would be required for every size of envelope

The gumming apparatus, shown separately in Figs. 888 and 889, requires some further notice. The cam 11, Figs. 884 and 888, gives motion to the lever 11′, and this to the wheel 11″, and the axis to which it is affixed. The prolongation of this axis carries a lever *e*, and is hinged to a small frame *ff*, which carries the gummer 10. The curved lever *e′* is linked to the opposite side of the frame *ff*, and serves to retain it always horizontal to the plane of the table T, so that when the former moves forward on to the envelope, its action is very similar to that of the closing of a parallel ruler. This gummer 10



[illegible] ION THE [illegible]

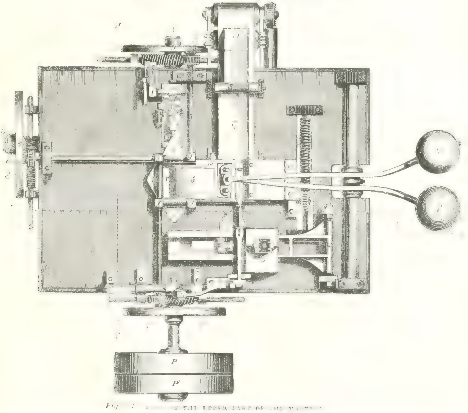


Fig. [illegible] F THE UPPER PART OF THE [illegible] takes its gum from the endless blanket 20, Fig. 889, whenever [illegible] 21, the [illegible] being regulated by the small [illegible] 23. The endless blanket is moved forward at each interval of motion of the gumming apparatus, by means of a pawl or catch attached to a lever worked by the axis 11″, and working in a ratchet wheel 22, fixed to one of the rollers of the endless blanket. In Fig. 888, the two positions of the gumming apparatus are shown.

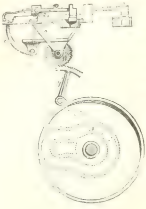


Fig. 888.

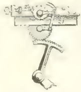


Fig. 889.

As the principal cam revolves at the rate of about one revolution per second, it is necessary to feed the machine when in motion with a blank envelope at that rate. If the boy neglects to feed at the proper time, *i.e.* on the completion of one revolution, two things happen; the first and more serious one is, that the gummer would place gum on the small table T, so that the next blank envelope would be spoiled; secondly, the envelope which had been previously folded, and which by the arrangement of the taking off fingers is left projecting a little from the box, would be knocked up in the box, in consequence of which the succeeding envelope would enter the box with so much difficulty, as to be crumpled up and spoiled, and it might also spoil several others. Both of these consequences are prevented by two stops, moved by the boy as soon as he fails to insert an envelope at the proper moment. The first stop being slid forward, touches a small lever 24, attached to the axis carrying the gummer 10, and lifts up this lever and the gummer as the frame is descending upon the table T; so that by this contrivance, as long as the stop remains in position, the gummer does not come in contact with the table: the second stop catches a projection 13‴, affixed to the axis of the fingers 13″, which are adjusted so as to turn in a small arc of a circle, so that as the saddle 13′ retreats along the slide 12, the fingers turn upwards and away from the projecting or *leading* envelope, as it is termed, which was previously folded. The slide in moving brings a projecting piece on the axis against a stop 14, which places the fingers in their usual position, and so long as the lad ceases to feed the machine (except, of course, when it is not at work) he leaves both these stops at rest; but as soon as he has fed the machine, he instantly removes them, and the operations proceed in the order previously described. By these simple contrivances, the waste of the machine is reduced to the small quantity already noticed. But it may be asked, Instead of these complicated provisions, why not adopt the apparently simpler course of stopping the machine, by shifting the strap from the fast pulley P, to the loose pulley P′? The answer is, that it is impossible either to stop or to start the machine instantly; for as the machine makes one whole revolution in a second, its several parts have a momentum due to that velocity, and could not be arrested in less than 3 or 4 seconds; but by the ingenious contrivances above described, no time is lost, except that required for the feeding of one envelope; and should the boy see a broken sheet of paper or find that two are stuck together, and require a brief instant to remedy the defect, he can thus secure it without stopping the machine.

This ingenious and highly interesting machine was patented on the 17th March, 1845, by Edwin Hill and Warren De la Rue. An apparatus for cutting out the blanks was also included in the same patent. Previous to this date, envelopes were cut out by means of chisels, the paper having been roughly cut to shape, and then held between two templates of the proper form. The envelopes were then folded by hand with the assistance of a common bone knife or folding-stick. A quick hand could on an average fold about 3,000 per day. Now the machine folds with a precision not attainable by hand, from 45 to 60 per minute; this is the average including all causes of stoppage; so that in a day of 10 hours, from 27,000 to 30,000 envelopes are completed, which when seen in a pile, appear as if they had all been cut to size by a knife.

In this machine, economy of space is as remarkable as rapidity of production and excellence of workmanship. This machine does the work of 10 skilful folders, and does not occupy more space than would be required by one folder. But it may be asked, is this really an advantage? Does not one of these machines deprive ten pairs of human hands of the means of earning bread? We have already examined this question in other articles of our Cyclopædia, and we again answer, No! If the 10 envelope folders who are superseded by 1 of these machines could absolutely do nothing else but fold envelopes, then they would suffer; but no one pretends that 10 busy, active and intelligent young women who have attained skill in this business, are incapable of quickly attaining skill in other occupations where activity and skill are required. Other occupations, it is true, may not be readily procured, and these 10 folders may for a time suffer from want of employment; but if our principle is true, that improved machinery increases employment among operatives, it is true in this case also, as the following details will show. The envelope-folding machine has made envelopes cheap, and as adhesive envelopes are convenient, the demand for them has surprisingly increased. Previous to the year 1839, envelopes were not used, because the Post Office charged double postage if one piece of paper were enclosed in another. The date of the Act for adopting postage reform, was 17th August, 1839, and the date of the commencement of charge of postage by weight instead of by the number of enclosures, was the 5th December, 1839, when a fourpenny rate was adopted. On the 10th January, 1840, the penny postage rate commenced; envelopes were now introduced, but they were not much used. On the 6th May, 1840, stamps and stamped envelopes were introduced, and so convenient were the latter found, especially when made adhesive, that the use of them rapidly extended. Now we may get some idea of the demand for envelopes by the following table, showing the number of letters which have passed through the Post Office during the last twenty years. In 1839, before the introduction of the penny postage, the gross annual number of letters passing through the Post Office in the United Kingdom, was estimated at 76 millions.

In 1840 it was 169 millions.		In 1846 it was [illegible] millions.	
1841	,, 196½ ,,	1847	,, [illegible] ,,
1842	,, 208½ ,,	1848	,, [illegible] ,,
1843	,, 220½ ,,	1849	,, [illegible] ,,
1844	,, 242 ,,	1850	,, [illegible] ,,
1845	,, 271½ ,,		

	Letters delivered in Great Britain.	Of which were delivered— In Scotland.	In Ireland.
1851	. . . . 360,647,187	[illegible]	. . . . . [illegible] mil.
1852	. . . . 379,501,499	[illegible]	. . . . . [illegible] ,,
1853	. . . . 410,817,489	1[illegible] ,,	. . . . . [illegible] ,,
1854	. . . . [illegible]		
1855	. . . . [illegible]		
1856	. . . . [illegible]	[illegible]	. . . . . [illegible]
1857	. . . . [illegible]	51 ,,	. . . . . [illegible] ,,
1858	. . . . 523,[illegible]	50¾ ,,	. . . . . [illegible] ,,
1859	. . . . 544,[illegible]	52 ,,	. . . . . [illegible] ,,
1860	. . . . [illegible]	5[illegible] ,,	. . . . . [illegible] ,,

The whole number of letters, general and local, delivered in the London district in 1860 was 157,000,000. The whole number of letters delivered in the same London district in which they were posted was 41,500,000. About one-fiftieth of the letters delivered in the United Kingdom were from places abroad. The number of registered letters was nearly 1,500,000, or one registered to about 400 ordinary letters. Nearly 71,000,000 newspapers were delivered in 1860, and about 11,700,000 book packets. Nearly 2,000,000 letters were returned to the writers, owing to failure in the attempts to deliver them. More than 10,000 letters were posted without any address at all. About 30,000 newspapers could not be delivered. Nearly all the letters now posted are in envelopes, and this brings us back to the subject of the present article.

If the greater part of the 564,000,000 letters posted in 1860 were enclosed in envelopes, and most written communications sent by hand are (to save the trouble of wax or wafers) enclosed in adhesive envelopes, remembering too the large quantities of envelopes exported to the colonies, &c., we have a vast and increasing trade in the manufacture of these useful articles. To produce these envelopes by hand at their present price, would be simply impossible: to charge a higher price in order to remunerate the army of folders required to produce so vast a quantity, would be to destroy the envelope trade; for unless envelopes continue to be sold at an exceedingly cheap rate, the demand for them would decline far more rapidly than it originated. Now the effect of this increased demand for envelopes is to multiply labour. In the *first* place, the demand for paper is so great, that at the present time a scarcity of rags is being felt; in the *second* place, the tool-makers and the engineers are actively employed in supplying envelope machines, and the subsidiary apparatus, and keeping them all in repair; *thirdly*, new punches are being constantly made for stamping the crest or the initials of the consumer on his envelopes, or for embossing fancy patterns thereon; while the embossing-press is kept in constant activity. *Fourthly*, the demand for gum for adhesive envelopes is now so large, as to have originated a new branch of manufacture to supply it. [See GUM.] We might go on to point out the moral effects of the envelope machine; how, by increasing the facilities for letter writing, the intellectual occupations of the people are increased, their mutual sympathies kept alive, and the great cause of popular education encouraged; but we trust that enough has been said to show that the introduction of so active a producer as the envelope-folding machine, is not an industrial evil.

In the Great Exhibition, a second folding machine by M. Rémond was shown. It differs from the machine already described in some respects, which we may briefly notice. This machine is self-feeding, for which purpose a hollow arm moving backwards and forwards, is alternately exhausted and filled with air. In its exhausted state it arrives just over a pile of blank envelopes or lozenges, the top one of which clings to it by atmospheric pressure: the arm then moves on, becomes filled with air, and drops the blank upon a moveable table. A dabber then falls down and presses the envelope against two gum troughs which contain a sponge and resemble the wick-holder of a lamp, they being so adjusted as to place the gum where it is wanted. A rectangular frame or plunger next forces the paper into a rectangular opening. Each of the four corners is then inclined inwards by a puff of condensed air which issues from a slit near it. The hollow plunger then falls down a second time, and completes the fold by three internal projections concealed from view. The envelopes are removed singly by hand, placed in a press, and then slightly pressed. This machine is not nearly so certain in its action as that previously described.

EPROUVETTE, see GUNPOWDER.

EPSOM SALTS, see MAGNESIUM.

EQUILIBRIUM (from [illegible], equal [illegible]). A body is said to be in equilibrium when the forces which act upon it mutually counterbalance each other, or when they are counterbalanced by some passive force or resistance. Thus a body suspended from the end of a thread is in equilibrium, because the attraction of gravitation, which would cause it to fall, is counterbalanced by the resistance of the thread, and by that of the point of suspension. A body may be in equilibrium without any apparent resistance. Thus a fish may be in equilibrium in water, and a balloon in air; but the weight which would cause the fish to sink or the balloon to fall, is exactly counterbalanced by other forces. We may, however, regard all bodies which appear to us to be at rest, as being actually in a state of equilibrium, or equally balanced between or among forces which destroy each other. The conditions of equilibrium are determined by the science of STATICS, (στατὸς, standing still,) as regards solids; and by HYDROSTATICS (ὕδωρ, water, and στατος,) as regards fluids.[1]

EQUIVALENTS, see ATOMIC THEORY.

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[1] [illegible] Mechanics [illegible] Rudimentary Series, Second Edition, [illegible]

ERMINE, see FUR.

ESCAPEMENT, see HOROLOGY.

ESSENTIAL OILS. The *essential* or *volatile* oils may be regarded as the odorous principles of vegetables, and the term is generally applied to these products, as obtained by distilling the plant with water; in some cases the oil is thus derived from the fresh or salted plant, as from roses and orange flowers; in others, from the dried plant; and sometimes it may be pressed out of the cellular structure containing it, as in orange and lemon peel. These oils are frequently obtained from every part of the plant, but there are generally peculiarities in the oil derived from different parts of the same plant; thus, with regard to the orange-tree, the leaves, flowers, and fruit, each yield a distinct oil. The boiling-points of almost all these oils are above that of water, but their vapours are carried over with steam at 212°, and condensed with it in the refrigerator; a portion of the oil is, however, always retained in solution in the water, constituting what are called *medicated* and *perfumed waters*, while the remainder either floats upon the surface or sinks to the bottom, according as it is less or more dense than distilled water. The greater number of these oils are lighter than water, and in such cases, the distilled product is received into a vessel called a *Florentine receiver*, Fig. 890. It is conical in form, and at the side is a spout *b c* communicating with the bottom, the orifice *c* of the spout being much lower than the mouth *a* of the receiver. The distilled product being poured in this vessel, the oil B separates from the water A, and occupies the upper part of the vessel. The water as it rises above the bend of the spout flows off at *c*, while the essential oil may be from time to time removed by means of a pipette. In some cases the oil and water are separated from each other by pouring the contents of the recipient into a funnel, the tube of which is closed by the finger, and, when the oil has collected upon the surface, the water is suffered to run from beneath it, and the oil is transferred into a bottle. When the oil is heavier than water, these operations are of course inverted. Instead of a common funnel, the *separator*, shown in Fig. 891, may be conveniently employed, as the oil may be retained in it, and at the same time preserved from contact of air. The distilled water, being in these cases already saturated with the oil, should be retained for a repetition of the distillation. The produce of oil is sometimes stated to be increased by adding salt to the water in the still, so as to elevate its boiling point. When, as in the case of oranges, lemons, and similar fruits, the oil is expressed instead of distilled, the yellow part of the rind is rasped off and pressed in hair-cloth bags; the expressed juice separates, on standing, into two distinct portions, the inferior of which is aqueous, and the superior oily. The oil thus obtained is generally more fragrant than when heat has been resorted to, but it is at the same time less pure; and, although it gradually clarifies itself, by depositing the substances held in mechanical suspension, it retains colouring and other matters in permanent solution, so that when dropped upon paper it leaves a stain, and does not produce a clear alcoholic solution. There are some of these oils which are produced in such small quantities, or which are so delicate and evanescent, as not to admit of collection by either of the preceding methods, such as the fragrancy of the flowers of the jasmine, the violet, the tuberose, the lime-tree, the narcissus, and some others. To obtain these, the fresh flowers are stratified with layers of cotton imbued with some inodorous fixed oil; this gradually absorbs the volatile oil or perfume of the flower, and when saturated with it, the cotton is digested in alcohol, which abstracts the essential from the fixed oil, and an odoriferous *essence* is obtained. Sometimes the cotton is distilled with water or with alcohol, and the oil separated by that process; it is, however, generally too delicate to admit of such treatment without great deterioration, or even entire destruction.

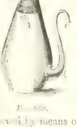

Fig. 890.

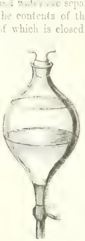

Fig. 891.

The essential oils are applied to many useful purposes; the cheapest and most abundant are used in the manufacture of paints and varnishes, and are occasionally burned in lamps; others are employed in pharmacy and medicine, and are generally powerful and diffusible stimulants; others, and especially such as possess agreeable odours, are used for the various purposes of perfumery. In general, these oils are ready formed in the plants whence they are derived, but in some cases they are no doubt generated by the action of water upon peculiar principles existing in the vegetable. Hence, also, some plants which are naturally inodorous, yield a strongly scented volatile oil after they have been subjected to fermentation, as in the case of the *lesser centaury* (Centaurium minus). There are also a few instances in which essential oils have been artificially produced.

When fresh and pure, the essential oils are mostly colourless, or nearly so; but they are generally of various tints of yellow or brown, or soon become so under the influence of air; some few of them are green and blue, and several of them, even after having acquired colour, lose it under the continuous influence of light. Their odours more or less resemble those of the fresh plants whence they are derived, but are less agreeable, partly in consequence of concentration, for they become more pleasant when diluted by, or diffused through a large bulk of air, or when attenuated by solution in some inodorous vehicle.

Liebig has observed that the odour of these oils is greatly influenced by their chemical relations to air and water; that they all absorb oxygen; and that those which do so most rapidly, are most odorous.

If non-oxygenized oils (hydrocarbons) be distilled off quicklime, either in vacuo, or in a stream of carbonic acid, the product is so far inodorous, that it is difficult, under these circumstances, to distinguish oil of lemons, of juniper, and of turpentine, from each other; but after exposure to air, especially if spread upon a piece of paper, their natural characteristic odours return, and they at the same time become viscid and resinous, so that it would appear as if the odour was the result of the act of oxidizement, as is the case with metallic arsenic.

They are almost all possessed of strong, aromatic, and often extremely pungent and burning flavours, and many of them are poisonous. They have not the greasy feel of the fat oils, but, on the contrary, are rather rough upon the cuticle, and cause a cork moistened by them to squeak when twisted into a phial. They are inflammable, and burn with a bright, but often very smoky flame.

The specific gravity of the essential oil fluctuates between the extremes of 0.846 and 1.097. The greater number of them are lighter than water, as shown in the following table of their average specific gravities; but the results can only be considered as approximate, for the densities appear to vary with the mode of distillation and the period of that process at which they are collected, the first portions which pass over being often less dense than the last. They are also influenced by the condition of the plant, the period at which it is cropped, the age of the oil, and its greater or less exposure to air; so that the same kind of oil, produced in England, and elsewhere, often varies considerably. Thus Proust found camphor in the oils of some of the *labiatæ* of Spain, while there was none in those of France.

SPECIFIC GRAVITIES OF THE ESSENTIAL OILS.

Oil of [illegible]	[illegible]
,, ,, (Foreign)	[illegible]
,, bergamot	[illegible]
,, cajeput	0.926
,, calamus	[illegible] to 0.954
,, cassia	1.071
,, chamomile (English, from flowers only)	0.9083
,, ,, Foreign	0.9289
,, cinnamon	[illegible]
,, cloves	1.034 to 1.052
,, copaiva	0.878
,, cubebs	[illegible]
,, cumin	[illegible]
,, dill	0.994
,, elemi	0.849
,, fennel	0.997
,, juniper (English)	[illegible]
,, ,, (Foreign)	[illegible] to 0.9110
,, lavender (English, from flowers only)	[illegible]
,, ,, (English, from the whole herb)	[illegible]
,, lemon peel	[illegible]
,, marjoram	[illegible]
,, nutmegs	[illegible]
,, orange peel	0.8881
,, pennyroyal	[illegible] to 0.9780
,, pepper	0.8640
,, peppermint (English)	0.9070
,, pimenta	1.021
,, rosemary	0.9118
,, rue	[illegible]
,, sassafras	[illegible]
,, spearmint	[illegible]
,, spike lavender	[illegible]
,, turpentine	[illegible]

The greater number of the volatile oils appear to be mixtures of two, and sometimes of three different products; one of which is a *hydrocarbon*, and the other an *oxyhydrocarbon;* and in many cases the latter, when isolated, assumes a concrete form, constituting a species of *camphor*. Berzelius applies the term *stearoptene* and *elaioptene* to these solid and fluid products; (from στέαρ, fat, or ἔλαιον, oil, and πτηνὸς, volatile;) and they often admit of separation by the application of cold, which causes the camphor to solidify; or by distillation, when the portion of the oil which is destitute of oxygen passes over at a lower temperature than that which contains oxygen: but when these mixed oils are thus distilled, their separation is never perfect, the more volatile hydrocarbon always carrying over with it a portion of the less volatile oxyhydrocarbon; so that other methods are resorted to, entirely to deprive the former of oxygen, amongst which, the action of fused caustic potassa is one of the most efficient, for by it the whole of the oxygen (and part of the carbon) is abstracted in the form of carbonic acid. This variable composition of the essential oils explains the inequality of their boiling points; but frequently the cause of the rise of the thermometer during the progress of distillation, depends upon a progressive decomposition of the oil, in which case more or less gas is generally evolved. Although nearly all these oils are, as just stated, constituted either of carbon and hydrogen, or of carbon, hydrogen, and oxygen, there are a few which contain sulphur and nitrogen, but these are of a very peculiar character.

The essential oils being dissolved in small quantity, by water, to which they communicate taste and odour, the London Pharmacopœia directs the extemporaneous preparation of several of these waters, by adding the oil (subdivided by trituration with a little carbonate of magnesia) to simple distilled water, instead of distilling the water off the herb itself; a little alcohol is also directed to be added to the water, with a view of preserving it from change; but Mr. Warington has shown, that alcohol has the opposite effect, and that distilled waters which keep well without such addition, are liable to acetification with it. Some of these oils apparently enter into chemical combination with definite proportions of water to constitute crystallizable compounds, or camphors. They dissolve abundantly in absolute alcohol, and in ether.

Exposed to the influence of oxygen, or air, the volatile oils undergo two distinct series of changes; some of them seem directly to combine with oxygen to form crystallizable, and, in many cases, acid compounds; but in other cases the action of air changes the oil into a resinous substance, a portion of its hydrogen being probably converted into water, so as to leave excess of carbon in the residue. The action of chlorine upon many of these oils is attended by the immediate production of hydrochloric acid, and compounds of chlorine and of hydrochloric acid, with the remaining elements of the oil, are formed. The same happens with iodine and with bromine; and in some cases the decomposition of the oil thus effected so intense as to give rise to inflammation. The action of acids, and other agents, varies considerably with the nature of the oil; the action of nitric acid is also for the most part intense, and frequently attended by the formation of a resinoid product.

Amongst the essential oils which are destitute of oxygen, (the hydrocarbons of the series,) there is a remarkable identity of composition; they contain between 88 and 89 *per cent.* of carbon, and between 11 and 12 *per cent.* of hydrogen, proportions which are expressed by the formula C_5H_4; so that their varieties may be generally regarded as isomeric or polymeric modifications of a hydrocarbon so constituted; being namely, C_5H_4, or $C_{10}H_8$, or $C_{20}H_{16}$, or $C_{15}H_{12}$, points which are best determined by the respective densities of their vapours, it being obvious that in respect to the equivalent, or atomic weight of the compound, as deduced from its combinations, it [illegible] cations only admit of distinction by their action upon polarized light, some of them rotating the ray to the *right*, others to the *left*, and others transmitting it uninfluenced, showing that although there is identity of composition, of atomic weight, and even of density of vapour, there is nevertheless a difference in their [illegible].

In consequence of the high price of many of these oils, they are variously adulterated, sometimes with alcohol and with fixed oils, and sometimes with the cheaper essential oils. When alcohol is used, it may be detected by agitating the adulterated oil with water, or with a saturated solution of common salt, and its quantity appreciated by the diminution of bulk which the oil so treated sustains: this falsification is also indicated by a slight increase of temperature when the oils are mixed with water, and which is not observed when they are pure. Alcohol may also be abstracted from an essential oil by means of fused chloride of calcium. The volatile oils, when pure, dissolve perfectly in all proportions in the fixed oils, without interfering with their transparency; but not so when the former are adulterated with alcohol: in that case, a few drops of the adulterated oil added to a perfectly transparent fixed oil, produces more or less turbidness. The admixture of a *fixed oil* is ascertained by the greasy stain which remains when a drop of the oil is evaporated before the fire from a piece of bibulous paper; but some of the genuine essential oils, especially such as are old, or have been exposed to air, often under these circumstances leave a stain, which, however, is rather resinous than greasy. When an essential oil thus adulterated is rubbed between the finger and thumb, it generally has more or less of a distinct greasy feel; or if distilled with water, the fixed oil remains behind; if mixed with about thrice its bulk of alcohol, of sp. gr. 0.84, the fixed oil is also separated. [See COHESION FIGURES, App.]

The adulteration of a *high-priced* with a cheaper essential oil, is more difficult of detection, and requires for its discovery a practical acquaintance with the odour, flavour, and other distinctive characters of the genuine oil, which can only be attained by experience. When oils are falsified with oil of turpentine, its characteristic odour is often covered, till the adulterated oil is dissolved in a little alcohol, and the solution mixed with water, when both the odour and flavour of the turpentine become manifest. The refractive indices of the adulterated oils generally differ from those of the genuine article, and Dr. Wollaston suggested a form of instrument for their determination, which has been improved by Mr. Cooper: it is often useful, but the refractive power of the genuine oil varies too much to render it satisfactorily available.[1]

ETCHING, see ENGRAVING.

ETHER. The action of sulphuric acid upon alcohol aided by a moderate heat, leads to the production of a remarkable volatile liquid called *sulphuric ether*, or simply and more correctly *ether*, because it contains neither sulphur nor sulphuric acid. It was first described by Valerius Cordus, in 1540, who published precise directions for making it. After which it seems to have been forgotten until 1730, when Frobenius in a paper in the Philosophical Transactions, described its singular properties. A note at the end of this paper by Godfrey Hankwitz, Boyle's operator, states that experiments had been made upon it both by Boyle and by Newton. In modern chemistry the process of etherification has been minutely studied.

Ether was obtained until recently by simply distilling a mixture of sulphuric acid and alcohol. The following are the directions for the process:—"Mix with 16 ounces of sulphuric acid an equal weight of rectified spirit, and distil about 10 fluid ounces; add 8 ounces of spirit to the residuum in the retort, and distil about 9 fluid ounces; or continue the operation until the contents of the retort begin to rise, or the product becomes considerably sulphurous; mix the two products, or if the mixture consist of a light and a heavy fluid, separate them: add potash to the lighter as long as it appears to be dissolved: separate the ether from the solution of potash, and distil about $\frac{9}{10}$ths of it to be preserved as *ether sulphuricus*, the sp. gr. of which ought to be at most .750."[2]

When this process is conducted on a small scale, glass vessels may be used, but on a large scale, a leaden still should be employed. At Apothecaries' Hall, the ether-apparatus consists of a leaden still, which is heated by means of high-pressure steam carried through it in a spiral pipe. A tube enters the upper part of the still for the purpose of introducing the alcohol. The still-head is of pewter, and is connected by about 6 feet of tin pipe with a capacious condensing apparatus cooled by a current of water. The receivers are of pewter with glass lids, and furnished with a side tube to connect them with the delivering end of the condensing pipe. From the highly inflammable nature of ether and its vapour, great care must be taken to remove the operation from the vicinity of fire; hence the use of heating by steam.

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[1] Abridged from Professor Brande's 'Manual of Chemistry,' [illegible]

[2] [illegible] 'Experimental Examination of the London Pharmacopœia.'

The old method of preparing ether is both wasteful and inelegant. By [illegible] method, alcohol is allowed to drop into the hot acid, in which case the form of apparatus shown in Fig. 892, may be used for preparing ether upon a large or a small scale. A is the vessel for holding the alcohol; it has a ground stopper, so that when the stopcock is turned partially open, the alcohol may drop with the required degree of rapidity into the funnel B, the tube of which is elongated, and terminates by a small aperture near the bottom of the flask C, which is placed in a copper sand-bath D, supported on a ring, and heated by the gas-burner E. The temperature of the mixture in the flask can be noted by means of the thermometer F. A wide glass tube G, conveys the vapours from the flask to the condenser H, which is surrounded by cold water in the vessel I, and delivers its contents into the receiver K.

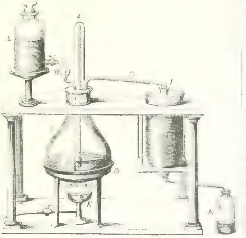

Fig. 892.—[illegible] PREPARATION [illegible]

A mixture of 8 parts by weight of concentrated sulphuric acid and 5 parts of rectified spirit of wine of sp. gr. 0·834, is introduced into the flask, and heated up to 300°, when it boils. Alcohol is then allowed to drop in through the long funnel, and by regulating the quantity admitted, and by turning the gas more or less on, the temperature of 300° is maintained as steadily as possible, and the liquor in the flask kept in brisk ebullition. In this way all the alcohol that is admitted may be converted into vapour of ether and of water, and the mixed vapours passing through G are condensed in H, while ether and water fall into K, and arrange themselves into separate layers, the water being at the bottom.

The bulk of the liquor in the flask remains pretty constant if the operation be well managed. The great point is to keep up the temperature so as to produce rapid ebullition. Etherification takes place between 260° and 310°, and if too much alcohol or too weak an alcohol be used, so as to reduce the boiling point below 260°, the alcohol distils over almost unchanged; if, on the other hand, too [illegible] be employed, the temperature rises to 320° or thereabouts, and olefiant gas and other products are generated.

The theory of the formation of ether may be understood from the following details. When common rectified spirit of wine is mixed with an equal volume of concentrated sulphuric acid, heated to the boiling point and left to cool, an acid known as the *sulphovinic acid* is formed. If the resulting fluid be diluted with water, and neutralized with chalk, a large quantity of sulphate of lime is formed. On filtering and pressing the mass through a cloth, a clear solution is obtained, which must be evaporated to a small bulk, filtered, and left to crystallize. Beautiful colourless transparent crystals of sulphovinate of lime are thus formed. By substituting carbonate of baryta for chalk in the above process, a similar salt is procured, from which the hydrated sulphovinic acid ($C_4H_5O, 2SO_3 + HO$) may be procured by precipitating the baryta by dilute sulphuric acid, and evaporating the filtered solution *in vacuo*. It is a very sour liquid, readily decomposed by heat; and it is upon the formation and subsequent decomposition of this acid, that the formation of ether is supposed to occur.

When the mixture of alcohol and sulphuric acid, in the process for making ether, is heated so that it boils at 260° or under, the sulphovinic acid that is formed is resolved into sulphuric acid (SO_3), which remains behind, and alcohol (C_4H_5O, HO), with a mere trace of ether (C_4H_5O), which goes over in vapour as already noticed. But when the mixture has its boiling point between 260° and 310°, the sulphovinic acid is resolved into hydrated sulphuric acid (SO_3, HO), which remains behind, and ether (C_4H_5O), accompanied by only very small quantities of alcohol, which pass over in vapour.

By the old process of making ether from a mixture of equal parts alcohol and sulphuric acid, the conditions as to temperature could not be complied with. At first the temperature was too low to yield much ether, and towards the end, long before the sulphuric acid had been decomposed, it was too high, and olefiant gas and its accompanying products were produced. But by the *continuous process*, *i.e.*, by allowing alcohol to [illegible] with the sulphuric acid as fast as it is liberated, and sulphovinic acid is reproduced as fast as it is decomposed. In this way a small quantity of sulphuric acid is made to etherify an almost indefinite quantity of spirit, and it might be indefinite were it not that the sulphuric acid slowly volatilizes, partly in the state of oil of wine, and it is this loss of acid which is the only limit to the duration of the process. The ether of commerce usually contains alcohol and [illegible] water, and if long prepared may also be slightly acid. Perfectly pure ether is prepared by shaking the ether of commerce in a corked vessel with about twice its bulk of water; the ether will rise and occupy the surface, after which it is drawn off, and a sufficient quantity of quick-lime is added to it, by which means the water [illegible] is removed. The mixture of ether and lime is next distilled; the first third that distils over is pure ether, free from alcohol and water.

Ether is a highly volatile, transparent, colourless, limpid liquid, of a penetrating, and to most persons agreeable odour, and a pungent and sweetish taste. It is very exhilarating, and produces a remarkable species of intoxication, when its vapour mixed with air is respired. By proper management, a continuous insensibility to pain may be kept up, by causing the patient to inhale this vapour. Hence its use in surgical operations; but in many respects, chloroform is preferable for this purpose. [See CHLOROFORM.] Ether is neither acid nor alkaline: it has a high refractive power, and is a nonconductor of electricity. It is slightly soluble in water, 9 parts of which take up 1 of ether. Washed ether retains about a tenth part of water, or according to Liebig, 36 parts of pure ether dissolve 1 part of water. The specific gravity of ether at 68° is 0.713. It boils at mean pressure at 96.5°; but the boiling point is influenced by the nature and state of the vessel in which the experiment is made. [See EBULLITION.] Ether is so exceedingly volatile that it cannot be poured from one vessel into another without loss; hence it is dangerous to take the stopple out of a bottle of ether near a lighted candle. Vapour of ether is much denser than atmospheric air, in the ratio of 2.58 to 1. If a few drops of ether be moved round in a deep wine or test glass, so as to wet the sides, the glass will soon be filled with vapour, which vapour can be poured like water or carbonic acid into another glass, from which it will displace the air. A lighted match applied to the glasses will detect the presence of the vapour in the second glass, and its disappearance from the first. A drop of ether on the hand produces cold, in consequence of the rapid evaporation. Professor Brande has given an elegant experiment to illustrate the production of cold in this way. Let a few drops of ether fall upon a drop of water, so as to cover it; then blow upon it with a blow-pipe, and the water will soon freeze into a lump of ice. Ether has not been frozen, even when exposed to a temperature of 166° below zero. Ether should be preserved in well stoppled bottles, or in sealed tubes, in a dark place. Exposed to air and light, a little acetic acid is formed in it, and it becomes acid to tests. When ignited, ether burns away with a bright and slightly sooty flame, leaving no residue, and producing carbonic acid and water. Mixed with about ten volumes of oxygen, it explodes violently by an electric spark. When vapour of ether is passed over red hot platinum wire formic and acetic acids are produced.

Alcohol and ether mix in all proportions. Ether dissolves, more or less, iodine, bromine, sulphur ($\frac{1}{100}$th), phosphorus ($\frac{2}{100}$ths), the fixed and volatile oils, many of the resins, caoutchouc, various forms of extractive, the alkaloids, and some other vegetable principles. Sulphur and phosphorus may be obtained in small crystals by evaporating the ethereal solutions.

Ether has been found by analysis to contain C_4H_5O, so that it differs from alcohol, $C_4H_6O_2$, by HO, the elements of water. Alcohol also furnishes a number of *compound ethers*, as they are called, by the action upon it of different substances; and the constitution of these compound ethers admits of comparison with ordinary salts by putting in the place of the metal a hypothetical salt-basyle, named *ethyle*, containing C_4H_5. This substance may be supposed to form haloid-salts by combining directly with chlorine, iodine, bromine, &c.; and the *oxide of ethyle*, or common ether, taking the place of the basic metallic oxides, may combine with oxygen-acids and form salts. Although ethyle has not yet been isolated, and is therefore a purely imaginary compound, yet its adoption has been found to simplify in a happy manner the theory of the ethers. The following is a table of ethyle compounds:—

Ethyle	C_4H_5
Oxide of ethyle, or ether	C_4H_5O
Hydrate of the oxide of ethyle, or alcohol	C_4H_5O, HO
Chloride of ethyle	C_4H_5, Cl
Bromide of ethyle	C_4H_5, Br
Iodide of ethyle	C_4H_5, I
Cyanide of ethyle	C_4H_5, C_2N
Nitrate of the oxide of ethyle	C_4H_5O, NO_5
Hyponitrite of oxide of ethyle	C_4H_5O, NO_3
Oxalate of oxide of ethyle	C_4H_5O, C_2O_3

EUDIOMETER, an instrument invented by Priestley, and since produced in a variety of forms by different chemists, for ascertaining the composition of atmospheric air under various circumstances. The use of the eudiometer, termed *eudiometry*, has since been extended to all gaseous mixtures, but especially to the determination of the quantity of oxygen which they contain when resulting from the operations of chemical analysis.

The principle of the eudiometer, so far as it relates to atmospheric air and oxygen gas, is to expose them to the action of some substance, solid, fluid, or gaseous, which will combine chemically with the oxygen, and leave the gas or gases with which it is mixed unacted upon. For example, the eudiometer of Seguin is a glass tube 8 inches long, and about 1 inch in diameter, and open at one end; it is filled with and inverted in mercury: a small piece of phosphorus is then put under the open end of the tube, and it rises to the top of the mercury, where it is melted by holding a hot iron near it. A measured portion of the gas to be examined is then passed into the tube; the phosphorus inflames on each addition of the gas, and the mercury rises, owing to the condensation of the oxygen. The quantity of the residual gas is determined by transferring it into a graduated tube, and the difference between the quantity submitted to experiment and that which remains, indicates the amount of oxygen absorbed. Berthollet, in his eudiometer, employed a similar method, only instead of igniting the phosphorus, he allowed it to combine with the oxygen by slow combustion. In the course of six or eight hours the whole of the oxygen disappears, and its quantity is indicated by the rise of the mercury or the water in the tube; while the amount of nitrogen is shown by the quantity of gas left in the tube.

Volta determined the quantity of oxygen in a gaseous mixture, by mixing therewith a known volume of hydrogen gas, and then firing it by means of an electric spark. As it is known that every two volumes of hydrogen combine with and condense one volume of oxygen, the contraction of volume in the mixture will be one to the oxygen. One form of Volta's eudiometer is shown in Fig. 893. It consists of a very thick, graduated glass tube, from 18 to 24 inches long, and about 4 lines internal diameter: it is open at one end, and closed at the other. Near the top A, the tube is perforated, and platinum wires are fixed in the holes, the ends within the tube being at such a distance apart as to allow the passage of the electric spark between them: on the outside the wires are furnished with hooks or knobs. Near the opening B the tube is perforated at the side, and furnished with a glass cock, which is closed after filling the tube with the gas to be examined. This prevents any loss of gas in consequence of the great expansion which precedes the condensation of the gases. When the spark has been passed, the cock is turned under water, or mercury, and the fluid rises in the tube: the condensation is then noted by bringing the fluid within and without the tube to the same level.

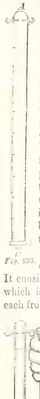

Fig. 893.

Another modification of Volta's eudiometer, contrived by Dr. Ure, is shown in Fig. 894. It consists of a glass syphon, the internal diameter of which is from $\frac{2}{10}$ to $\frac{4}{10}$ of an inch: its limbs are each from 6 to 9 inches in length, and about $\frac{1}{2}$ an inch asunder. The open extremity is slightly funnel-shaped; the other extremity is hermetically sealed, and is furnished with two platinum wires, made tight by fusing the glass round them. The instrument having been graduated, is filled with water or mercury, and the gas transferred into it: then being held upright, part of the fluid in the open leg is displaced by inserting a glass rod. The open leg ought to contain at least two inches of air between the thumb and the mercury, in order to serve as a sort of recoil spring. The open leg being grasped by the hand, the thumb is to be placed lightly over the aperture so as to close it, and at the same time to touch one of the wires: a spark taken from the conductor of an electric machine, or from the knob of an electrophorus, to the other wire, passes through the gas, ignites it, and is conducted off by the thumb. The gas in expanding depresses the fluid beneath it, and the air below the thumb acts as a spring to restrain the violence of the explosion. When the explosion is over, the subsequent condensation will be felt by the thumb being pressed down to the orifice by the atmospheric pressure: on gently sliding the thumb on one side, and admitting the air, the column of mercury in the sealed leg will rise more or less above that in the other: mercury is then to be poured in till the equilibrium is restored, and the resulting volume of gas is then read off.

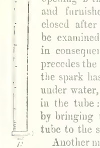

Fig. 894

An elaborate form of eudiometer has been contrived by M. Regnault, a description of which will be found in the fourth volume of that gentleman's excellent *Cours de Chimie*, Paris, 1850.

EVAPORATION is the process by which a liquid gradually disappears or diminishes in bulk by the formation of vapour at its surface. In the process of EBULLITION, vapour forms at every point of the liquid mass. It is a matter of daily experience, that water evaporates into the atmosphere at all temperatures, however low. The water deposited by a shower of rain soon dries up, even in winter, and in the dry warm weather of summer ponds disappear, and brooks and running waters diminish in volume. The process of spontaneous evaporation applies also to other liquids. Faraday has shown that vapour rises from mercury at common temperatures, at least from 60° upwards. He placed some mercury in the bottom of a glass bottle, and attached a piece of gold leaf to the bottom of the stopple: in the course of a few weeks the gold became white by amalgamating with the vapour which ascended from the mercury. Some solids also, such as camphor, disappear by the process of spontaneous evaporation.

It was formerly supposed that evaporation was due to an affinity between the particles of air and the particles of the liquid exposed to it, whereby a combination was formed, and a constant absorption of liquids by the air took place. Dr. Dalton was the first to establish the true philosophy of the process: by a series of beautiful and simple experiments he was led to the conclusion that the vapour of water, and probably of most other liquids, exists at all temperatures in the atmosphere, and is capable of bearing any known degree of cold without a total condensation, and that the vapour so existing is one and the same thing as *steam*, or vapour of 212° or upwards. The idea, therefore, that vapour cannot exist in the open atmosphere at a lower temperature than 212°, unless chemically combined therewith, he considered as erroneous: it has taken its rise from a supposition that *air* pressing upon vapour condenses the vapour equally with *vapour* pressing upon vapour; a supposition we have no right to assume, and which he apprehended will plainly appear to be contradictory to reason, and unwarranted by facts: for when a particle of vapour exists between two particles of air, let their equal and opposite pressures upon it be what they may, they cannot bring it nearer to another particle of vapour, without which no condensation can take place, all other circumstances being the same; and it has never been proved that the vapour in a receiver from which the air has been exhausted, is precipitated upon the admission of perfectly dry air. Hence, then, we conclude, till the contrary can be proved, that the condensation of vapour, exposed to the common air, does not in any manner depend upon the pressure of the air.

To clear up this question Dalton determined by experiment, *first*, the expansive force of dry air for each degree of temperature between 32° and 212°. He also found that 1,000 cubic inches of air at 32° expanded into 1,376 on being heated to 212°.[1] He also ascertained, *secondly*, the force of pure steam in contact with

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(1) Gay Lussac's result, obtained soon after Dalton's, was 1.375

water for each degree throughout the same range; and *thirdly*, he found at what rate dry air expanded when put in contact with water, and heated through the various degrees of that range. The result was, that at any particular temperature the expansive force of dry air in the first case, added to the force of vapour in the second, was exactly equal to their joint expansive force in the third. Hence there was either no chemical combination between air and vapour, or, if it existed, it was quite inert. When other gases were substituted for air, the vapour gave the same results, and similar results were obtained when other vapours were treated as steam. The quantity of vapour in a given space was found to be independent of the presence of air or other gases, and to depend entirely upon the temperature. For example, if a few drops of water be put into a dry flask at 32°, a very small quantity of vapour will be formed: if the temperature be raised, the quantity of vapour will be increased in proportion. If the temperature be again lowered, some vapour will be condensed, and the portion still remaining in the elastic form will be due to the temperature. The result is the same as respects the vapour whether air be present in the flask or not. At a given temperature the same amount of vapour is formed in a vacuum, as in the same space occupied by air, with this difference, that in a vacuum evaporation is very rapid, and comparatively slow in air, the aërial particles apparently offering some mechanical resistance to the saturation of the space with vapour. The space is said to be *saturated* when it contains all the vapour that can be produced at a given temperature: so that any addition of vapour or diminution of temperature produces condensation.

Regarding vapour as an elastic or gaseous body, its elastic force is measured by the height of the column of mercury which it will support. If a barometer tube (such as Fig. 95 or 96, article BAROMETER) be employed, filled with mercury, and standing in mercury as in the figures, and a few drops of water be introduced at the open end without removing the tube from the cistern, the water will rise up into the Torricellian vacuum, and expanding into vapour, will, by its elastic force, depress the mercury in the tube. The amount of this elastic force or tension may be measured by comparing the height of the mercury in the tube with that in a good barometer near it. The temperature of the vapour in the vacuum may be determined and regulated by surrounding the upper part of the tube with a vessel containing water and a thermometer. If the barometer stand at 30 inches, and the mercury in the tube at 29 inches, then the tension or elastic force of the aqueous vapour will be expressed by 1 inch of mercury, or $\frac{1}{30}$th part of the mean elasticity or tension of the atmospheric air. If the water in the outer vessel be heated to 212°, the whole of the mercury will be forced out into the cistern, for the elastic force of vapour of water at that temperature is 30 inches of mercury: *i. e.* it will support a column of mercury at that height, just as the atmosphere does at the level of the sea.

These experiments explain the meaning of the valuable tables given in scientific books of the elastic force of steam at different temperatures. The following is a specimen of such a table, which gives also the weight of a cubic foot of vapour at the temperature named.

Temp. Fahr	Tension in inches of mercury.	Weight of a cubic foot.
32°	0.216	2.53grs.
40°	0.280	3.23 ,,
50°	0.400	4.53 ,,
60°	0.560	6.22 ,,
70°	0.770	8.39 ,,
80°	1.060	11.33 ,,
90°	1.430	15.00 ,,
212°	30.000	257.22 ,,

The relative volatility of other liquids, and the elastic force of their respective vapours, may be estimated by their effects on the column of mercury in the barometer tube. Thus, if five barometers be placed side by side, and some water be let up into the vacuum of the first, some alcohol into the second, ether into the third, and sulphuret of carbon into the fourth, each column will be depressed by the elastic force of the vapour of each liquid at the existing temperature of the air.

As evaporation is entirely confined to the surface of a liquid, so its amount depends upon the amount of surface exposed. Thus, in certain processes in the useful arts, where crystals are formed by evaporation, or where liquids are exposed to the air for other purposes, large shallow vessels are employed, or the liquids are allowed to trickle over extended surfaces. [See SALT.] By covering the surface of water with a film of oil, evaporation is suspended altogether. The process goes on most rapidly when a dry wind is blowing over the surface of the liquid: hence in some factories where large quantities of liquids are to be evaporated, a current of hot air is passed over their surface, instead of applying fire beneath them. Evaporation is slow, when stagnant air rests on the surface of the liquid, for when this becomes saturated with vapour, the presence of this vapour puts a stop to the process. Hence the use of revolving fans, made to fly rapidly over the surface of the liquid [see BEER, Fig. 113], so that as fast as the vapour is formed it is wafted away. It will be seen, from the following table, how different the results are in still air from those obtained during wind. This table shows the force of vapour at different temperatures, and the rate of evaporation per minute from a circular surface 6 inches in diameter.

Temp.	Force in In. of Mercury.	Calm.	Breeze.	High Wind.
212°	30.000	120.00grs.	154.00grs.	189.00grs.
85°	1.235	4.92 ,,	6.49 ,,	8.04 ,,
75°	0.906	3.65 ,,	4.68 ,,	5.72 ,,
65°	0.657	2.62 ,,	3.37 ,,	4.12 ,,
55°	0.476	1.90 ,,	2.43 ,,	2.98 ,,
45°	0.340	1.36 ,,	1.75 ,,	2.13 ,,
35°	0.240	0.95 ,,	1.22 ,,	1.49 ,,
25°	0.170	0.67 ,,	0.86 ,,	1.05 ,,

Professor Daniell, who drew up this table from the experiments of Dalton, remarks that these amounts of evaporation are only maintained when the incumbent air is perfectly dry. If vapour be already present, as is always the case in the atmosphere of this climate, the quantity capable of evaporating at any given temperature will be the quantity indicated in the table, diminished by the quantity already in the incumbent air.

When a liquid passes into the state of vapour, there is a great absorption of heat, which becomes latent. This conversion of sensible into latent heat is necessary to the existence of a vapour, and it takes place at whatever temperature the vapour is formed. The source of heat in ebullition is supplied by the fire; but in spontaneous evaporation it is usually furnished, either by the liquid itself, or by the vessel containing it. Advantage is taken of this fact in the cooling of water and wine by means of porous vessels, named *alcarrazas*, which being filled with water, and hung up in a current of air, the fluid slowly penetrating to the outside of the vessel is converted into vapour by depriving the water within of a portion of its heat. If a wine bottle be placed in the cooler, its temperature is lowered with that of water. Wine or water may also be cooled by wrapping a wet towel round the bottle or vessel containing it, and exposing it to a draught of air. In India the bed curtains are sprinkled with water, by the evaporation of which the air is cooled. The danger of wearing damp clothes arises from the cold produced by evaporation. In the animal economy, heat is generated in the system, and given out by the body. If this heat be abstracted faster than a new supply is formed by the process of respiration, the sensation of cold is produced, whereas, if the heat be not removed exactly in proportion as it is formed, a feverish sensation is experienced. The former effect is produced by the evaporation arising from damp clothes, and the general result is what we term a cold.

By the skilful application of a known principle, some very surprising results may often be obtained. For example, if some ether be poured upon the surface of water contained in a flat vessel, and placed under the receiver of an air-pump, the ether will boil as soon as the air is removed, and its rapid evaporation will soon cause the water to freeze, thus exhibiting the singular spectacle of two liquids, one resting upon the other, the one boiling and the other freezing; in a few minutes the one entirely disappears in the form of vapour, while the other solidifies in the form of ice. Some remarkable examples of freezing will be given in the article ICE. [See also APPENDIX.]

Various instruments have been contrived for measuring the quantity of vapour existing in the atmosphere, or its relative degrees of dampness and dryness. Those which merely indicate the presence of moisture in the atmosphere, more or less, are termed *hygroscopes;* those which measure its quantity are more properly named *hygrometers.* To the former class belong certain animal and vegetable textures which absorb moisture with great readiness, and by their changes of dimension which ensue, measured on a graduated scale, indicate roughly the amount of vapour. Thus the untwisting of a piece of cord, or the beard of the wild oat, the elongation of a thin slice of whalebone, the elongation or contraction of a human hair, &c., have all been used. When these substances are exposed to a dry atmosphere, they give up the moisture which they have imbibed, and return more or less accurately to the dimensions which form the zero of the scale. Instruments of this kind are, however, liable to uncertainty in their construction, so that two instruments of the same kind by different makers, or even by the same maker, do not always agree in their indications, and such instruments always become deteriorated by time.

A beautiful and simple method for determining the elastic force of vapour at any time existing in the air, was adopted by Dalton, and afterwards by Daniell, who used it as the basis of his elegant hygrometer. It is well known that the moisture of the atmosphere will become condensed upon the surface of a colder body brought into contact with it. Thus, when a glass on a warm day is filled with well-water, its surface becomes bedewed with moisture. By pouring this cold water into a second glass, carefully drying the surface of the first, and returning it back again, and repeating the operation many times, or as often as may be necessary, the water becomes slowly warmer. The temperature of the water must be carefully noted with a small thermometer, as also the precise temperature at which the glass ceases to be bedewed. This is called the *dew-point*, and is in fact the temperature of water, whose vapour is of the same elasticity as that of the air of the place where the observation is made. In winter, or in very dry situations, the water may be cooled down by mixing a little ice, or salt and snow with it, and if these cannot be procured, a small quantity of sulphate of soda, or of carbonate of soda, added to the water, will reduce its temperature below that of the atmosphere, so as to produce a deposit of dew upon the glass. The glasses used should be thin. The observation may be made more precise by using a small cup of thin silver, of the capacity of half an ounce, gilt on the outside. The water is to be cooled by cautiously adding a few grains of a powder composed of equal parts nitrate of potash and muriate of ammonia, stirring it up with the bulb of a small thermometer.

But the dew-point may be most conveniently observed with the assistance of Daniell's hygrometer, Fig. 895. It consists of two thin glass bulbs, *a b*, connected together by a bent tube *c*. Enclosed in the bulb *b*, is the elongated bulb *d* of a very delicate thermometer *d e*, the scale of which rises into the arm *b c*. This bulb *b* being filled with ether, is heated until the vapour issues freely from an aperture *f* in the bulb *a*, which is then hermetically sealed. If the operation has been well performed, the ether in the bulb *b* will boil by the heat of the hand, as in the case of Franklin's pulse glass, [see EBULLITION, Fig 785,] which we have no doubt suggested this instrument to its ingenious inventor. The bulb *a* is covered with a piece of muslin. The stand is of brass, and the transverse socket c at the top is made to hold the glass tube in the manner of a spring. A small thermometer k, inserted into the pillar of the stand, enables the observer to compare the temperature of the air with that of the dew-point. In using this instrument, the covered bulb a is to be wetted with a few drops of ether, the rapid evaporation of which cools this bulb, condenses a portion of the vapour within the bulb a, the consequence of which is that the ether in the bulb b immediately begins to evaporate, and in doing so, cools its exterior surface. This diminished temperature will be made evident by the falling of the mercury of the enclosed thermometer *e d*, and also by the formation of a ring of moisture on the outside of the bulb *b*, coinciding with the surface of the liquid. The exact temperature at which this ring of dew begins to form on the bulb *b*, must be noted on the internal thermometer, for that is the dew-point. The temperature will go on falling a few degrees, and dew may be plentifully formed on the bulb, but the first observation may be confirmed by noting the temperature at which the dew disappears from the bulb: this will be found to be identical or nearly so with the temperature at which it began to form, and this is the dew-point. If there should be a difference of 1° or 2°, the mean may be depended on as being accurate.

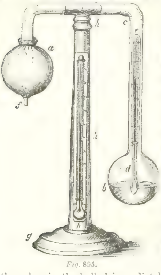

Fig. 895.

Having ascertained the dew-point, we can, by mere inspection of the tables prepared for the purpose, determine the elasticity and density of the aqueous vapour, its weight in a cubic foot of air, the degree of dryness either upon the scale of the thermometer or of the hygrometer, and the rate of evaporation. When the air is saturated with moisture, the precipitation of dew is instantaneous, for the dew-point coincides with the temperature of the air. In this country the degree of dryness measured in thermometric degrees seldom reaches 30°, that is to say, the dew-point is seldom 30° below the temperature of the air; but in the Deccan, with the temperature of the air at 90°, the dew-point has been seen as low as 29°, making the degree of dryness 61°.

Professor Daniell remarks that, "the more accurate mode of expressing the moisture of the air from an observation of the temperature and dew-point, is by the quotient of the division of the elasticity of vapours at the real atmospheric temperature, by the elasticity at the temperature of the dew-point: for, calling the term of saturation 1,000, as the elasticity of vapour at the temperature of the air is to the elasticity of vapour at the temperature of the dew-point, so is the term of saturation to the observed degree of moisture. Thus with regard to the observation in the Deccan,—

$$1.430 : 0.194 :: 1000 : 135.$$

The fourth term is the degree of moisture on the hygrometric scale."[1]

The formation of dew on the great scale of nature is a wise and beneficent arrangement for getting rid of the superfluous heat absorbed during the day, and for supplying the earth with moisture. After sun-set—and frequently, in shady places, long before—the heat absorbed by the earth begins to be radiated into space, and as this process goes on, the earth's surface becomes cooled below the temperature of the air which rests upon it. This may be easily verified on a clear night by using two thermometers, placing one on the grass and suspending the other a few feet above it. The suspended thermometer will often indicate a temperature many degrees above that of the thermometer on the grass, thereby showing the earth to be colder than the air immediately above it. Under such circumstances, the effects which are observed when a glass of cold water is taken into a warm room, are produced here: the cold earth precipitates the moisture contained in the air in the form of dew, not equally over the whole surface, as might at first be supposed, but most abundantly on those substances which need it most, such as grass and vegetables, while the gravelled walk or compact road by the side will often be quite dry. The reason for this is, that the former are good radiators of heat, and consequently cool down quickly, while the latter radiate badly, and consequently maintain their temperature. Under a cloudy sky radiation is checked, and the earth being prevented from cooling down, little or no dew is formed. On a clear night the radiation is often so powerful, and the consequent reduction of temperature so great, that the dew is frozen into what is called *hoar-frost*.[2]

EXCENTRIC. A wheel in which, whatever be the figure of its periphery, the axis is removed from the centre, is said to be *excentric*. There are various kinds of excentrics, and they are of great importance in converting one kind of motion into another; such as continuous circular motion into alternating or intermitting rectilinear motion, or into curvilinear though not rotatory motion. They also furnish

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(1) Introduction to the Study of Chemical Philosophy. 1839. See also the third edition of the Meteorological Essays. 1845.

[2] The true theory of dew was first established by Dr. Wells, in a small pamphlet published in 1816, a work which Sir John Herschel "earnestly recommends for perusal to the student of Natural Philosophy, as a model with which he will do well to become familiar." This pamphlet is now difficult to procure, but the reader who desires further acquaintance with this subject will find an analysis of it in a little work entitled "The Dew Drop and the Mist," written by the Editor, and published in 1847 under the direction of the Christian Knowledge Society. A new and enlarged edition was published in 1860.

means for producing from the uniform speed of one revolving shaft, rotatory motion of continually varying speed in shafts placed in connexion with it.

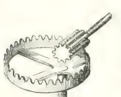

Fig. 896.

Such an application is shown in Fig. 896, in which an excentric crown-wheel is made to produce some of the complex movements of a planetarium.[1] The crown-wheel is mounted excentrically upon a shaft which revolves with a uniform speed: a pinion driven by it is made so long that it may be acted upon either by that portion of the periphery of the crown-wheel which is nearest to its axis, or by the opposite portion of the periphery. As the distance from the axis of the crown-wheel to the nearest point of the pinion is little more than one-third of the distance from the axis to the furthest point of the same, and as the velocity of the axis or shaft is uniform, it follows that the pinion will be driven nearly three times as fast when in contact with that part of the periphery of the crown-wheel which lies furthest from the axis, as when in contact with the part which intersects it at the nearest point, while every intermediate portion of the periphery of the crown-wheel will impart a different, but intermediate velocity. Such a combination of wheels might be driven by the pinion, in which case, supposing the pinion to have a uniform velocity, that of the crown-wheel, or rather of its axis, will vary. Further variations might be introduced by making the periphery of the crown-wheel of some other form than circular.

The following is a case in which a rod A B, Fig. 897, is to be raised and depressed between the guides

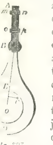

Fig. 897.

m n, *o p*, by means of a continued circular motion. Let C be the centre of this circular motion, or a section of the revolving axis. Upon this axis C is fixed a circle D E excentric to it, O being its axis, and C O the degree of eccentricity. This circle D E works in a circular opening of the frame B E D, fixed to B A by a joint at B. As the axis C and the circle D E form one piece, and as C is fixed in position, the effect of turning the axis C must be to raise and depress B A between the guides, the power being proportional to a perpendicular let fall from C upon B D. When this perpendicular vanishes, which happens when the line C O coincides with B O, the rod A will be at its lowest or its highest point.

EXPANSION, see Heat.

EXPLOSION. A sudden and violent expansion of an aëriform or other elastic fluid. It differs from expansion in being momentary, whereas expansion is a gradual power acting uniformly for some time. See Gunpowder—Fulminating Powder—Mercury—Gold—Steam, &c.

EXTRACT. This term is usually applied in Chemistry to the product of an aqueous decoction; but in pharmacy it is applied to that portion of any vegetable substance which had been dissolved by digesting it in any menstruum, and afterwards reduced to a thick consistence by distilling off the menstruum if valuable, or by evaporating it away if not worth preserving. Extracts are very numerous, and comprise a great variety of substances, but the nature of the ingredients varies according to the methods employed to prepare them. The greatest care must be taken to avoid injuring them by heat. Hence they should be evaporated in a water bath, or by steam not exceeding 212°. They may also be evaporated at much lower temperatures in vacuo [See Sugar], or over sulphuric acid [See Ice]; and many of the extracts used in medicine may be so obtained, of much greater activity than when prepared in the usual way. Professor Brande remarks, that in the preparation of extracts, *uniformity* is the great object, for whether half a grain or two grains of the more powerful extracts is a dose, is of less importance than the certainty that they are as far as possible of a given power.

FACTORY. According to the definition given in the 73d section of 7th Vic. c. 15, "the word 'factory,' notwithstanding any provision or exception in the Factory Act, shall be taken to mean all buildings and premises situated within any part of the United Kingdom of Great Britain and Ireland, wherein, or within the close or curtilage of which, steam, water, or any other mechanical power shall be used to move or work any machinery employed in preparing, manufacturing, or finishing, or in any process incident to the manufacture of cotton, wool, hair, silk, flax, hemp, jute, or tow, either separately or mixed together, or mixed with any other material, or any fabric made thereof; and any room situated within the outward gate or boundary of any factory, wherein children or young persons are employed in any process incident to the manufacture carried on in the factory, shall be taken to be a part of the factory, although it may not contain machinery. But this enactment shall not extend to any part of such factory used *solely* for the purposes of a dwelling-house, nor to any part used *solely* for the manufacture of goods made entirely of any other material than those here enumerated, nor to any factory or part of a factory used *solely* for the manufacture of lace, of hats, or of paper, or *solely* for bleaching, dyeing, printing, or calendering; and the enactments of this Act, respecting hours of labour, shall not apply to any young person employed *solely* in packing goods in any warehouse or part of a factory not used for any manufacturing process, or for any labour incident to any manufacturing process."

The factory system of England may be said to have taken its rise from the moment that the genius of Arkwright had accomplished that series of discoveries, and that clever adaptation of the discoveries of others, which resulted in the construction of the admirable machinery used in the cotton manufacture. To accommodate that machinery, a new description of building was necessary. The spinning-wheel and the loom, and even the spinning-jenny, if of small size, might be set up in the workman's cottage; but the water-frame, the carding-engine, &c. required more space, and also more power than the cottager could supply. Arkwright himself set the example of the sort of buildings that should be erected to work the machinery in, and to meet the new demands of the trade. He erected an extensive building in Manchester, at the cost of 4,000*l*., while in Derbyshire and elsewhere he and his partners expended upwards of 30,000*l*. in like manner. It is true that mills somewhat similar to those of Arkwright had been erected previously for the throwing of silk, but these were few in number, and of comparatively small importance.

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[1] This contrivance is by Huyghens, and is given by Professor Willis in his "Principles of Mechanism."

The progress of the factory system, when once it had become identified with the cotton trade, was rapid in the extreme. Its advantages were so great, that it would have been impossible, after once experiencing them, to return to the old system. The more evident of these advantages are thus stated by Mr. Baines,—"The use of machinery was accompanied by a greater division of labour than existed in the primitive state of the manufacture; the material went through many more processes; and of course the loss of time and the risk of waste would have been much increased, if its removal from house to house at every stage of the manufacture had been necessary. It became obvious that there were several important advantages in carrying on the numerous operations of an extensive manufacture in the same building. Where water-power was required, it was economy to build one mill, and to put up one water-wheel, rather than several. This arrangement also enabled the master spinner himself to superintend every stage of the manufacture; it gave him a greater security against the wasteful or fraudulent consumption of the material; it saved time in the transference of the work from hand to hand; and it prevented the extreme inconvenience which would have resulted from the failure of one class of workmen to perform their part, when several other classes of workmen were dependent upon them. Another circumstance which made it advantageous to have a large number of machines in one manufactory was, that mechanics must be employed on the spot, to construct and repair the machinery, and that their time could not be fully occupied with only a few machines."

The introduction of steam power did not materially change the form of building required in a factory. Whether water or steam be the moving power, a cotton mill is an immense square building, frequently seven or eight stories high, with a tall chimney, and rooms perhaps two or three hundred feet in length, lighted by numerous windows, which as evening approaches are brilliantly illuminated, giving to the whole structure a remarkable appearance from without. But factories are not always of this lofty character; for near Leeds there is a striking exception in the case of one of Messrs. Marshall's flax mills, in which the stories are, as it were, placed side by side on the ground, and where the operations usually carried on one above another, are continued in an unbroken series on the floor of one enormous room, 396 feet long by 216 wide, equal to nearly two acres. The motives for this form of factory were, convenience of supervision, facility of access to machines, the power of sustaining uniformity of temperature and moisture, the absence of currents of air, which are so objectionable in ordinary mills, the simplicity of the driving gear, and the excellence of the ventilation. As this extraordinary one-story mill presents a good model of a factory where space and other circumstances will allow of its being followed, we shall describe it somewhat fully. It stands amidst the usual lofty, square, many-storied factories, from which it does not differ in the nature of the operations carried on, but in the greater convenience and simplicity of its arrangements. This magnificent room is five times larger than Westminster Hall, and seven times larger than Exeter Hall, London. The writer has, elsewhere, recorded the particulars of his visit to this mill, and the results of an attentive study of its organization, which were to the following effect:—The machinery is arranged in parallel lines, extending the whole length of the room, ample space being left for the operations of the attendants. The processes carried on are chiefly drawing, roving, spinning, doubling, and reeling, the dusty operations of dividing and heckling having been previously performed in another mill. Hot-water spinning is also carried on in this room, and with much less inconvenience than usual, in consequence of the space and abundant ventilation. The machines are mostly attended by young women; and a tablet attached to each machine states the number of spindles at work, the quantity of yarn being spun, or some other particular information belonging to the work. The lightness and airiness, warmth, and ventilation of this room, are admirable. The light is derived from the roof, which is formed of brick-groined arches, 66 in number, each 36 feet span, and supported by iron pillars to the height of 21 feet. In the centre of each arch is a conical sky-light, about 14 feet in diameter, and rising about 10 feet above the roof. From the points of these lights the used air of the room is allowed to escape. Beneath this room is an immense vaulted cellar, with brick pillars. This cellar is employed for a variety of useful purposes, one of which is, to supply hot air to the room above. This is done by means of a small steam-engine, working a large fan, which forces air through a series of 364 pipes, contained in two large steam-chests, which heat the air before it ascends into the mill. The temperature can be regulated by the quantity of steam which is admitted into the chests, or by allowing a portion of cold air to pass by without traversing the pipes. Valves and doors in the flues permit any temperature which is desired to be attained, or that degree of moisture which is essential to the process of flax-spinning. The cellar also contains the shafts for communicating motion to an immense assemblage of machines in the mill. These shafts are moved by a pair of steam engines of 100 horse power. This cellar also contains the gas and water-pipes, carpenter's shop and warehouses, and a set of baths both for hot and cold water. The operatives are entitled to the use of these on exhibiting a ticket of good conduct from the overlooker. The cold baths are gratis, but for a warm bath one penny is charged. Each bath is contained in a separate room, which is lighted with gas, and the whole is under proper regulation and control. The general details of this two-acre room, and of the immense cellar beneath it, scarcely excite more surprise than the novel use to which the roof of the building is applied. The approach to this is by a flight of steps within the room, on ascending which, we come out not on an ordinary flat roof, but into a grass-field, on which sheep are occasionally seen feeding. From the surface of this field rise what appear at first sight to be numerous greenhouses, but on approaching them, the whirl of the machinery below becomes visible, and they prove to be the skylights already mentioned. The presence of a grass-field in so novel a situation admits of easy explanation. The brick arches which form the roof of the great room were first covered on the outside with a coating of rough plaster, then with an impervious coating of coal-tar and lime, and to prevent this from cracking, a layer of earth, eight inches thick, was placed upon it, and sown with grass, which flourished well in that situation. The method of draining this field is not the least admirable contrivance of this remarkable building. The iron pillars which support the roof are hollow pipes, down which the rain-water passes into the sewer beneath. The upper extremity of each pipe is covered with a grating, to prevent solid substances from entering and stopping up the channel.

Admirable as these arrangements are, it is obvious that they can seldom be carried out: in most situations the many-storied mill will be a matter of necessity, however much the one-storied mill may be a matter of choice. A cotton-mill may be like Orrell's factory at Stockport, seven stories high, forming a massive and imposing structure of main body and wings, and losing, from its great extent and importance, much of the unpleasant effect given to factories in general by a multitude of windows on a flat unrelieved surface. This mill is considered by Dr. Ure to exhibit "in the collocation of its members" an instructive specimen of the *philosophy of manufactures*. He therefore gives the following exact description of it in his work bearing that title, a description which illustrates the arrangements of cotton-mills in general, and is confirmed in every particular by our own inspection of Orrell's celebrated mill. After naming the size and importance of the building, the central portion of which is 300 feet long and 50 feet wide, while the projection of the lateral wings is 58 feet in front of the main body, he says: "The moving power consists of two 50 horse steam-engines, working rectangularly together, which are mounted with their great gearing-wheel on the ground floor, at the end of the body opposite the spectator's right hand, and are separated by a strong wall from the rest of the building. This wall is perforated for the passage of the main horizontal shaft, which, by means of great bevel wheels, turns the main upright shaft, supported at its lower end in an immense pier of masonry, of which the largest stone weighs nearly five tons. The velocity of the piston in each of these unison engines is 240 feet per minute, which by the balance beam and main wheel is made to give to the first horizontal shaft 44.3 revolutions, and to the main upright shaft 58.81 revolutions per minute. As the one engine works with its maximum force, when the other works with its minimum, the two together cause an uniformity of impulsive power to pervade every arm throughout the factory, devoid of those vibratory alternations so injurious to delicate and finely poised mechanisms. The engines make 16 strokes per minute, of 7.6 feet each, and perform their task with chronometric ease and punctuality. The boilers for supplying steam to the engines and to the warming pipes of the building, are erected in an exterior building at the right-hand end of the mill, and transmit the smoke of their furnaces through a subterraneous tunnel to the monumental-looking chimney. By this means a powerful furnace draught is obtained, corresponding to a height of fully 300 feet." Orrell's mill spins warp yarn by throstles, weft yarn by mules, and weaves up both by power-looms. "Both systems of spinning, namely, the continuous or by throstles, and the discontinuous or by mules, require the cotton to be prepared on the same system of machines, and therefore they must be arranged subordinately to the preparation rooms. This arrangement has been considered in the true spirit of manufacturing economy by the engineer. As the looms require the utmost stability, and an atmosphere rather humid than dry, they are placed on the ground-floor of the body of the building, as also in a shed behind it, to the number of about 1,000. The throstle-frames occupy the first and second stories of the main building; the mules the fourth and fifth stories, each of these four apartments forming a noble gallery, 300 feet long by 50 wide, and 12 feet high. The third story is the preparation gallery, intermediate between the throstles and mules, as it is destined to supply both with materials. Towards one end of this floor are distributed the carding engines; towards the middle, the drawing machines for arranging the cotton fibres in parallel lines, and forming them into uniform slivers, or soft narrow ribands; and towards the other end, the bobbin and fly frames, or roving-machines, for converting the said slivers into slender porous cords called rovings. These rovings are carried downstairs to be spun into warp yarn on the throstle, and upstairs, to be spun into weft (or sometimes warp) yarn on the mules.

"The engine occupies an elevation of three stories at the right hand end of the mill. The stories immediately over it are devoted to the cleaning and lapping the cotton for the cards. Here are, 1, the willows for winnowing out the coarser impurities; 2, the blowing-machine for thoroughly opening out the cotton into clean individual fibres; and 3, the lapping-machine, for converting these fibres into a broad soft fleece like wadding, and coiling the fleece into cylindrical rolls. These laps are carried to the contiguous carding-engines, and applied to their feed-aprons. The winding-machines and a few mules occupy the remaining apartments in the right wing. The attic story of the main building is appropriated to the machines for warping and dressing the yarn for the power-looms. The other wing of the mill is occupied with the counting-house, store-rooms, and apartments, for winding the cotton on the large bobbins used for the warping-frame. A staircase is placed in the corner of each wing, which has a horse-shoe shape, in order to furnish in its interior the tunnel space for the teagle or hoist apparatus, for raising and lowering the work-people and the goods from one floor to another."

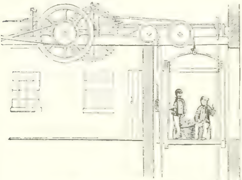

Fig. [illegible].—THE TEAGLE OR HOIST.

The Factory *teagle* or *hoist* thus alluded to, is a contrivance rendered necessary by the system of many-storied mills, to avoid the painful effort and loss of muscular energy involved in frequently ascending and descending numerous flights of stairs during the day. It is now adopted by most mill-owners, as a matter of economy as well as of due consideration for their work-people. It consists of a movable platform, capable of holding some half-dozen of operatives, and raised or lowered within an upright tunnel by machinery. The tunnel has doors in its sides, opening into the different floors of the factory, and the teagle, moving with a uniform and agreeable motion, is easily arrested at any one of these stories, while the work-people leave or enter on the platform. The same means is of course available for the conveyance of goods from floor to floor. The teagle is a strong frame-work of timber, six feet high, three sides of which are closed in with deal boards, while the fourth is left open, and faces the various doors of the tunnel. The frame is suspended by ropes from pulleys, and moved by machinery, which can be set in train with the common moving power. The accompanying illustration will sufficiently explain the action of this ingenious machine. Accidents occasionally occur in the use of the hoist, but these, as well as other accidents from machinery, are lessened in number by the care now taken to guard and fence off certain parts of machines considered dangerous. It is the duty of the government inspector, according to the act of 1844, to see that such precautions are taken, and to obtain correct returns of all accidents in a factory, which prevent the person injured from returning to his next day's work. The act also expressly requires, that if the inspector or sub-inspector shall observe in a factory any part of the machinery of any kind or description, or any driving-strap or band, not securely fenced, which he shall deem likely to cause bodily injury to any person employed in such factory, he shall give notice in writing to the occupier of the factory, or his agent, and if the occupier should object, or consider it unnecessary to fence such machinery, the matter is to be referred to arbitration, the arbitrators being persons skilled in the use of such machinery, and chosen, one by the inspector, the other by the occupier of the factory, a third being allowed, if necessary, to be chosen by the other two. If the decision of the arbitrators be, that it is unnecessary or impossible to fence the machinery in question, then the occupier will not be liable to the expenses connected with this reference: but if the decision be that it is necessary and possible for the occupier to fence the machinery, then the expenses of the reference will also fall on him.

The hours of labour in factories for women and young persons have been restricted, by the law, as amended by the act of 1850, to the interval between six o'clock in the morning and six o'clock in the evening, (including meal-times.) with exceptions during the winter months, and for the purpose of recovering lost time. On Saturday the working-hours are from six A.M. until two P.M. Respecting this latter arrangement an inspector (Leonard Horner, Esq.) thus wrote in November 1850:—"One of the greatest boons which the act of last session has conferred on the work-people, is the cessation from labour on Saturdays at two o'clock in the afternoon; two and a-half hours of continuous time, taken off that day from what could be worked under the Ten Hours' Act, being far more valuable to the work-people than the five separate half-hours from half-past five to six in the evening on the other days of the week. This boon has been acknowledged with not less gratitude by the adult males than by those whom the law takes under its protection. In some cases I have heard of, where an attempt was made to induce adult males to work after that hour, they have refused to comply, preferring the leisure to the additional pay. I have heard many emphatic expressions by the work-people of the satisfaction which this enactment has given, and the generality of masters fully admit the advantages of it to those they employ. Besides the direct benefit of their work-people having an [illegible]tunity of making their family arrangements, and having some recreation, their freedom from work on Saturday at that early hour is very likely to lead many to a more decent observance of Sunday than was possible under the old system."

A gratifying and unexpected result of shortening the hours of labour in factories has been, that nearly the same amount of work is turned off as before. "This is accomplished," says Mr. Horner, "partly by an increased speed of the machinery, but chiefly by the closer attention which the people give to their work, and are enabled to give by the shortened duration of the daily strain upon their physical powers. In one of the cases stated to me, there had been no increase in the speed of the machinery. The manager of one of the largest and best-managed cotton mills in my district, two months ago, of his own accord, made a statement to me, which I wrote down at the time, and which I now copy from my note-book:—'We are turning off the same amount of work as we did when we worked twelve hours. When I came to this mill nine years ago, the quantity turned off in the spinning department was the same as now; and there has been no change in the machinery, no increase in the speed. I set down the keeping up of the quantity entirely to the greater attention and activity of the hands. They are able to work better by the shorter time they are at it.'"

It was thought that the smaller pay of factory operatives, resulting from shortened hours of labour, would be felt as a great grievance; but, in fact, any diminution in the amount of wages earned at the factory is compensated by what is gained in other ways; thus the females are now themselves enabled to attend to various household duties, which must be discharged by some one, and for which, under the system of long hours at the factory, they had been obliged to pay for the services of a hireling: the money formerly spent in this way is now saved by the leisure afforded to the females of a family under the ten hours system, which enables them to perform their own duties themselves; and it is this saving of expenditure at home, which in great measure enables them to withstand a diminished rate of wages, accompanied by shorter hours of work. But some compensation for the reduction in the rate of factory wages is obtained by the male as well as the female members of a family under the present system; for they are enabled, by cultivating allotments of land and otherwise, to contribute their share towards eking out any deficiency in the amount of wages earned at the mill; and this latter advantage is much more extensively available, even in the case of factories situated in large towns, than would at first be supposed. For much more garden-ground is cultivated in the suburbs of large towns than formerly, and moreover it is no uncommon occurrence for hands who are employed at a factory, to be residing at the surrounding villages at the distance of four, sometimes five miles from their work.

A medical practitioner of long experience remarked, that the hands under the ten hours system enjoy an advantage which you cannot appreciate in money, but to the value of which they are keenly alive,—namely, improved health. Young girls and boys who have to walk long distances to and from their work, are greatly benefited by the extra two hours, in their health, and in means of improvement and enjoyment, so that it is not uncommon to hear them say, "I had rather give up a meal a-day than go back to the long hours."

In reporting their various plans to the inspector, one mill-owner says, "Last winter I offered about 200 square yards of land *gratis* to as many as wished to have it. Twenty men accepted the offer, and I have been amply repaid by seeing that it has been a great means of enjoyment to them and their families. They have been exceedingly attentive to their small gardens, having spent in them most of the time between the stoppage of the mill at six in the evening and dark. I have now several more applications, and intend to extend my plan, until every man in my employ who wishes to have a plot has got one. Following out the idea I received from you, I have determined upon offering prizes for the best flowers and have bought several very good framed and glazed engravings for that purpose. I also established a reading-room and library at the same time, which I am glad to say have exceeded my anticipations. Having a convenient room at liberty, I offered it to them with about 160 volumes of books. They pay one penny a-week as subscription, (those who choose to subscribe,) which sum purchases a sufficient number of newspapers and other periodicals. I believe that, merely in a pecuniary point of view, I am repaid by having better and more willing workmen; and I am quite confident it has been of incalculable service to them in every way."

The above plans are carried out in a comparatively rural district, and it may be said, "These things are all very well in such situations, but what can be done in the heart of a great town like Manchester?" Let the following account of what has been accomplished by a liberal and enlightened firm in that city be taken as an answer:—"For a number of years," says one of these estimable partners, "my brother and I had viewed with sorrowful feelings the woful state of ignorance existing in many of the mills of this extensive district; we saw that the workers evinced a very low tone of moral feeling; that their homes, to a very great extent, were ill-furnished, overcrowded, badly or not at all ventilated, and generally without those little comforts so necessary to render the home of a working man his place of rest and happiness. We found in tracing the cause of these evils, that they were mainly owing to the ignorance and intemperance of the adults who, having commenced their labours in the mill at, probably, six or seven years of age, had grown up in evil habits, and finding little comfort or attraction at home, had generally preferred the allurements of the public-house, thus perpetuating the evils of their position, instead of removing them."

The first attempt made by the masters to remedy this state of things, was to establish a Temperance

Society. Having succeeded in this, and seen it joined by more than three hundred of their people, they next directed their efforts to improve the physical comforts of the operatives. They introduced a complete system of ventilation into their works, fitting up about fifteen hundred ventilators of various kinds, suited to the different processes of spinning and weaving; the ventilation of one card-room alone costing 100*l.* The health and activity of the people were wonderfully increased thereby. One woman, about forty years of age, had long suffered from asthma by working in confined card-rooms. Every week, when she was laying out her wages in provisions, one shilling was regularly spent on a bottle of physic, to enable her, as she said, to breathe; after the ventilators were set to work, she became so much better that she discontinued the bottle altogether, and was able to breathe with comparative freedom. Open air exercises were introduced, with the same view of improving the physical condition of the operatives. An extensive gymnasium and play-ground was formed, running parallel with the large mill, and to connect this with the mill-yard, a six-feet wide promenade was made on the banks of the river. A giant stride and swings were erected in the play-ground for the use of the boys; skipping ropes, &c., were provided for the girls, and leaping-bars and skittles for the adults. A clear space of ground was reserved for games of marbles, merry-go-round, and other childish sports. The whole of the ground was surrounded by strong seats, where many enjoyed their meals in the open air. These steps being taken, the firm thought the way had been paved for mental and moral improvement. They therefore established a Mutual Improvement Society, in a small building near the factory yard. They supplied desks, maps, pictures, &c., and engaged two teachers, one at their own expense, the other remunerated out of the funds of the Society. Three young men employed in the concern also acted as unpaid teachers. At this institution four classes are held every evening, which, with the exception of the adult male class, are all free to the whole of the hands employed in the mill. In connexion with this Society is a library containing about six hundred volumes, the subscription to which is one half-penny per week; or, to that and a news-room, one penny per week. These rooms are open all day, so that at meal times, or when any of the hands are waiting for work, they may pass their time in reading the various newspapers and periodicals. Tea-parties are held once a-month, and fortnightly lectures are delivered in a large room in the mill. A Savings Bank, a Co-operative Society, and other useful institutions, unite with the usual and ordinary means of knowledge in a large town to raise the condition of these people.

While many honourable instances occur of mill-owners thus turning to the best account the increased leisure afforded to their work people, others are on record, in which the time is evidently grudged, and various attempts are made to get more labour out of the operatives, and thus to evade the operation of the act, and to gain an unfair advantage over those who strictly conform to its requirements. Various devices are employed to this end. The machinery is, perhaps, set in motion five or ten minutes before, and continued to five minutes after the appointed time of commencing and of breaking off work for meals, and this continued all through the day, gives the mill-owner about half an hour's extra work beyond that which the law allows him to get from his operatives. There is a case detailed in the report ending October 1850, in which the engineer swore that his orders from the head of the firm were to start the engine twenty-five minutes before the time stated in the notice fixed up for beginning work in the morning, to take fifteen minutes from each of the meals, and to run the engine till half-past six in the evening, instead of stopping at six. Another plan has been to find some loophole for pleading that the premises do not constitute a "factory" in the strict sense of the word, and are therefore not subject to factory laws. The definition of a factory, as given at the head of this article, is now, however, so plainly set forth, that there ought not to be any longer a doubt on the subject. The several devices alluded to, the object of which is to interfere with the operation of a most beneficial act, are altogether unworthy the character of the British manufacturer, and subject him to the contempt of his more liberal minded brethren, as well as to sundry vexatious prosecutions which it is the duty of the inspector to institute against him.

The possibility of combining with reduced hours of labour compulsory attendance of factory children at school, was proved by the successful practice of individual manufacturers before it came to be the law of the land. Sir Robert Peel, father of the late statesman, is said to have been the first to apply the principle in his cotton works at Fazeley in Staffordshire. The Messrs. Marshall, of Leeds, were the second, and it is to the great success which attended their liberal and enlightened efforts at the very time the subject was under the consideration of Parliament, that the admission of the principle in the Act of 1833 is mainly attributed. The law as it now stands is, that no child can be employed in a factory without attending school for three hours a-day on five days of every week, and that no child can be employed in a print-work without having had at least 150 hours of schooling, given in at least thirty days in the six months immediately preceding any day that it is employed. Where the factory schools are really good and efficient, the amount of instruction given in these half days is most satisfactory; no stronger proof of which can be given than by stating that, out of 61 effective schools, where the instruction is partly administered by pupil-teachers, approved and passed by the inspectors, and possessing varied and extensive knowledge, 28 of these pupil-teachers had received no other education than that of the factory schools. An intelligent master, speaking of factory boys, says, "They are among my best scholars. Three or four who have just left school, being 13, and entitled to work full time, had gone through the arithmetic three times, and were able to give solutions of the most difficult questions. Two others had not only worked through the arithmetic several times, but had also gone through Bridge's Algebra three times before they were 13 years of age. Their knowledge of geography, grammar, and other branches taught in the school, was also very good. I could add much to show the healthy state of education amongst the half-timers." The master here alluded to has introduced with perfect success the plan of the children buying their own books; a plan strongly recommended by Mr. Dawes (now Dean of Hereford) in his account of the King's Somborne school. The saving of expense to the school is a minor consideration in comparison with the advantages which the children derive from learning lessons at home. The plan has become popular with the parents, who seem to take great pleasure in seeing the progress of their children, and in being read to out of the excellent books taken home by the more advanced pupils. The real substantial value of the schooling becomes so evident that it makes a favourable impression on the parents also, and removes much of that indifference with which they too generally look on the efforts made to educate their children. The great amount of good manifestly accomplished by well-regulated schools makes it deeply to be regretted that their number is by no means equal to that of the imperfect and badly conducted schools at which factory children receive instruction. Unless the owner of the factory interest himself in the cause of education, the chances are that the children will be sent to the school nearest to their work, whatever that school may be. Speaking of the schools in his district, Mr. Horner is obliged to confess that out of 427 schools, 76 only—that is, not more than one-fifth—are good efficient schools; that 26 more are only tolerably good; that 146 are considerably inferior to these last; that 112 are so low in quality that the term indifferent is better than they deserve; and that 66 are not only of no value, but positively mischievous, as deceptions and a fraud on the poor ignorant parents who pay the school fees. These are schools scattered over the whole of Lancashire, and a few of them in the four northern counties. By law, therefore, children are compelled to go to school, and, of course, the reality and not the mockery of education was contemplated. But, unfortunately, the inspectors have no direct power to carry out the true object of the enactment. They can recommend and urge on the owner of the factory the duty of having the children removed from a bad school to a good one, and they can also annul a schoolmaster's certificate if he is unfit to instruct children "by reason of his incapacity to teach them to read and write;" but under terms so undefined they have scarcely any real power of interference; and the school may be held with impunity in a damp unventilated room, or without any approach to discipline or good order. This being the case, the greater responsibility falls on the manufacturers themselves, whose interest as well as duty it is to see that proper means are taken for the education of the children in their employ, and for the full development of the system which Government has devised for their benefit. Numerous are the instances where this responsibility is evidently felt, and where it has led to the most liberal and effective measures; but there are still too many millowners who in this respect allow things to take their own course, which is then almost inevitably a bad one. The wretched attempts at teaching which in some quarters supply the place of systematic and conscientious instruction, have doubtless led to an opinion, not unfrequently maintained and expressed—that the attempt to educate the children, proposed by the Factory Acts, has been a failure. It is only so when good schools are not within reach: where there are good schools, not only do the parents of the children, and the owners and managers of factories, with comparatively few exceptions, willingly avail them, but, as we have already said, the children make good progress: their 3 hours' daily attendance, from 8 to 13 years of age, is found sufficient to give them a very considerable amount of instruction. In a visit to a school near Oldham, taught by an able and zealous master, Mr. Horner heard a large class of factory children go through an excellent examination in English history, geography, and on the cotton plant, the chief monitor and examiner being a factory half-timer of 12 years of age. He names other instances of superior instruction given to factory operatives in infant, day, and evening schools, embracing the ignorant of all ages; and while dwelling on the liberal and benevolent policy of millowners, and the numerous advantages resulting to their people, he gives it as his deliberate opinion, that no description of employment for the working classes is more desirable than that in a well-regulated factory. He adds, "I am fully persuaded that as many instances of large pecuniary sacrifices, in the establishment of schools and other arrangements for the benefit of their workpeople, may be found among the owners of factories as among any other description of capitalists, whether in trade or in agriculture: if I said, more instances, I do not believe that I should overstate the case. There are doubtless many millowners who take no interest whatever in their people; missing by such indifference and neglect precious opportunities of doing the greatest public good, and of conferring lasting happiness on those around them, and on themselves. But this indifference is not confined to the occupiers of factories, for the condition of the largest proportion of the working classes of the United Kingdom too clearly shows that a want of a kind consideration of the employer for the employed is too widely spread, and is the root, I believe, of many of the evils in our social state; for something more than the payment of wages is needed to establish that friendly feeling towards the master, on which the security and well-being of society so much depend."

The last remark is one which should be ever in the recollection, not only of millowners, but of every employer of every grade. From the man who em ploys thousands, to the man who employs one or two domestic servants, the law of kindness and consideration equally applies; and no amount of payment of wages will atone for the neglect of the duties which that law requires. [See APPENDIX.]

FALL of BODIES, see p. 614.

FAN, see VENTILATION.

FARINA, see STARCH.

FAT, see CANDLE.

FAULT, see COAL—MINING.

FEATHERS. The preparation of the feathers of various birds for ornamental purposes forms the art of the *plumassier*, the French term for the artisan who works on them and combines them into their various forms, according as they are wanted for military use, or for the purposes of the toilette. The feathers most esteemed in Europe are those of the ostrich, which are accordingly imported from the African shores in considerable quantities. The west of Europe is chiefly supplied from the northern margin of the Great Desert. Those plucked from the living animal are far more beautiful, as well as more durable, than those taken from the animal some time after death. But the feathers obtained from recently killed birds have the same qualities as the living ones, and are far superior to the cast or dropped feathers. The plumage of the male bird, as is generally the case in all varieties of the feathered race, is very superior to that of the female, the fine drooping plumes on the back and near the tail being of the purest white, while those of the female are never free from a tinge of grey near the tip. In preparing the feathers for use, they are first tied together in bundles, plunged into tepid soap and water, and rubbed with the hand to free them from grease. After remaining in it for a few minutes, they are washed several times in pure water, as hot as the hand can bear, to rid them of the soap. Then they are bleached by being placed for a quarter of an hour in boiling water, holding in solution Spanish white, the solution being frequently agitated during the time, and the feathers washed in pure water on their removal. The next process is to pass the feathers quickly through a bath of cold water tinted with indigo, and the final one consists in sulphuring them in the same way as straw hats are done, and then hanging them up to dry. The ribs of the feathers are scraped to render them pliant, and the filaments are curled by drawing the edge of a blunt knife over them. Feathers are made to take a variety of beautiful colours, and of these rose colour is given with safflower and lemon-juice, and deeper shades of red by a boiling bath of Brazil wood, and subsequently a bath of cudbear. Indigo supplies the blues, and turmeric the yellows, alum being the usual mordant. Various shades are obtained by mixtures of the above dyes in different proportions.

Besides the ornamental purposes to which feathers are applied, there are highly useful ones, of which we all reap the benefit in the comfortable beds they supply, and in the facility with which their quills are converted into organs of communication. For bed feathers, those of the goose are employed, being dried in the air, in the sun, or in an oven, and also beaten many times. The down of the eider duck, a bird which is only found in northern countries, is remarkable for its lightness, and is very valuable for making quilts; but this down should never be employed for sleeping on, as it thereby loses its elasticity. [See EIDER DOWN.] Goose feathers unite all the qualities required in beds, namely, softness, elasticity, lightness, and warmth. After long use it becomes necessary to purify the feathers which have been used for beds, but this cannot be done by washing, as with wool or cotton. Sometimes they are put into a large metal cylinder, the double end of which receives the fire, and then agitated with sticks and beaten in order to be employed again; this operation, however, dries the feathers very much. A much better mode of purification consists in keeping the feathers moving in rotation, during a convenient time, in a cylinder with double partitions, between which steam is introduced. The feathers are exposed during several instants to the action of the steam of water, and are then dried by simple exposure to the air.

But as in the case of the ostrich, so in that of the goose, and of all the other birds whose plumage enters into the composition of beds, the feathers plucked from the living bird are decidedly the best, in respect of all those qualities which render them valuable. Hence arises the custom of plucking the live birds four or five times a-year. There is a remarkable district of our country, in which this practice is commonly pursued. Holland, a province in Lincolnshire, comprises the greater part of that division called the *Fens*. The character of this province is similar to the province of the same name in the Netherlands, after which it has been called. Nearly the whole of it appears to have been once covered by the sea, and only brought into its present state of productiveness by the persevering labour of its inhabitants. [See DRAINAGE.] The reedy districts which have not been reclaimed are well stocked with aquatic wild fowl, and the taking of them is a profitable employment to many persons who supply the markets of London with these delicacies. The decoys in this district are more numerous than in any other part of England, and are thus described:—"They are commonly formed around quiet pools, to which pipes made of bent willows, and covered with nets, gradually enlarging as they approach the water, are conducted. Into the large orifice of the pipes the wild birds are enticed by the tame ones, trained for that business, and who conduct them into the funnel, when the appearance of a man or his dog behind drives them to the most contracted part, where they are taken. The quantity of birds taken in some seasons is prodigious, amounting to some hundreds of thousands. They usually consist of teal, widgeon, and wild ducks; but occasionally wild geese, godwits, coots, ruffs and reeves, and whimbrels, are caught." In these fens, the keeping of geese, for the sake of the feathers, is a considerable branch of rural industry, and supplies a large part of the demands of the kingdom, both for beds and for pens. The feathers are plucked from the birds at three, four, and sometimes five different periods in the year. This is certainly a barbarous custom; but the breeders assert that, for their own profit, they pluck only those feathers which are so near falling off as to occasion little pain; those more firmly fixed, and which have some portion of blood at their end, being of very inferior value. This, however, is contrary to the assertions already made: the young ones are plucked as well as the old ones, experience having taught that, when plucked early, the future growth of the feathers becomes greater. During the breeding season, the birds are lodged in their owners' houses in wicker pens, which are arranged in rows, frequently in the bed-chambers. A gooseherd in attendance on the flock leads them daily to water, and assists them, on their return, to get into their several cells. The attendants are acquainted with each individual goose in the flock, and can commonly distinguish them by the tones of their voices. The preparation of the quills for pens will be noticed in the article PEN.

FECULA or FÆCULA, see STARCH.

FELSPAR or FELDSPAR. This important mineral is chiefly interesting in the useful arts on account of its furnishing, by a natural process of decomposition, the celebrated *kaolin*, used in making porcelain or china ware. [See CLAY.] Felspar is composed of silica 64·20, alumina 18·40, and potash 16·95. According to some chemists it may be regarded as a silicate of alumina with silicate of potash. Felspar also furnishes some soils with potash. According to Liebig, a single cubic foot of felspar is sufficient to supply an oak copse, covering a surface of 26,910 square feet, with the potash required by the trees for five years.

FELT—FELTING, see HAT.

FEN, see DRAINAGE.

FERMENTATION. Most vegetable substances which contain starch or amylaceous compounds, also contain substances which are capable under favourable circumstances of transforming starch into sugar. In many cases these substances are developed only at certain periods of vegetation, as, for example, the cereals in germinating contain a particular substance named *diastase*, which under certain conditions, explained in our description of the process of *malting* [see BEER], transforms starch into a soluble substance named *dextrine*, and then into sugar, provided the action be continued long enough. In these successive transformations there is no change in the chemical composition of the amylaceous substance; but it becomes soluble, and is thus carried into the circulation of the plant which it assists in developing.

Ripe fruits which contain much saccharine matter also contain a particular substance named *ferment*, which has the property under certain circumstances of decomposing sugar into alcohol and carbonic acid. But in order that the ferment may produce this effect, a certain temperature is required, as is also the contact of oxygen or of the atmospheric air. If grapes be subjected to pressure under mercury, and the juice received into a bell glass also full of mercury, it may be kept during many days without undergoing any change; but if a few bubbles of oxygen or of atmospheric air be introduced, a considerable disengagement of gas takes place during two or three days, and then ceases. If after this the juice be examined, it will be found that all the sugar has disappeared, and a volatile liquid, *alcohol*, has taken its place. This change does not take place in the ripe fruit itself so long as the skin is sound and all contact of the oxygen of the air with the juices is excluded; for without the contact of oxygen fermentation cannot take place.

This ferment is also produced when vegetable or animal matters spontaneously decompose. In brewing, a large quantity of this ferment, called *yeast*, *barm*, or *leaven*, is produced, a small portion of which being mixed with a solution of sugar soon produces fermentation, or the conversion of the sugar into alcohol and carbonic acid gas. So also when animal or vegetable substances, such as flesh, urine, gelatine, white of egg, cheese, gluten, leguminous substances, blood, &c. are exposed for some time to air and moisture, they undergo *putrefaction*, which is essentially a fermentation, in which the sugar contained in these various substances is transformed into alcohol and carbonic acid.

All saccharine substances under the influence of ferment undergo this decomposition more or less readily, and it is a characteristic of this class of organic products. The sugar of acid fruits, which turns the plane of polarization to the left; the solid sugar of dry fruits, and glucose, are rapidly decomposed by fermentation; but cane sugar requires a longer time. It is also a curious observation which polarization has revealed, that before cane sugar begins to ferment it is changed into fruit or grape sugar. Fresh yeast always contains a notable proportion of acid, and it is this acid which first changes the cane sugar into grape sugar; but as vegetable acids require much time for this transformation, the fermenting process is necessarily slow. Yeast deprived of this acid by washing, remains for a long time without any action on a solution of cane sugar; nor does fermentation commence until the acid is formed again by the changes which take place in the yeast in contact with air and water. If, on the contrary, we add to a solution of sugar the acid liquor proceeding from the washing of the yeast, the cane sugar will be transformed into grape sugar, which will enter into immediate fermentation by contact with the washed ferment.

100 parts of grape sugar yield by fermentation 48.88 parts of carbonic acid, and 51.12 of alcohol, so that the chemical elements of the ferment do not appear in the reaction, which may be expressed in the following equation:—

$$\underset{\text{Sugar.}}{C_{12}H_{12}O_{12}} = 4CO_2 + \underset{\text{Alcohol.}}{2C_4H_6O_2}$$

The decomposition of sugar by fermentation requires the immediate contact of the yeast, as may be proved by the following experiment:—the mouth of a bottle

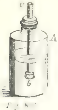

Fig. 899.

v, Fig. 899, containing a solution of sugar, is fitted with a perforated cork through which passes a wide tube *a b* open at both extremities, but the lower one, *b*, is closed by a piece of porous paper. A small quantity of yeast diffused through a little water is poured into the tube. In proportion as the saccharine solution penetrates the tube *a b* through the paper, a very active fermentation is developed, and an abundant liberation of carbonic acid; while in the bottle itself nothing of this kind takes place, and the sweet solution remains unchanged.

During the decomposition of sugar by fermentation, the ferment itself is destroyed, so that a small portion of this active principle is not capable of decomposing an indefinite quantity of sugar. If the quantity of ferment is too small compared with that of the sugar, its decomposition is effected before that of the sugar, a portion of which remains in the solution unchanged. If, on the contrary, too much ferment be present, the decomposition of the sugar is effected before that of the ferment, and the latter continues its action alone. If a fresh portion of a saccharine solution be now introduced, it produces fermentation therein until it is completely decomposed. The proportions which are best adapted to a rapid fermentation are 1 part cane sugar, 3 or 4 parts water, and ¼ part of fresh yeast. If the proportion of sugar be increased, the fermentation becomes less active, and it is entirely arrested in a saturated solution of sugar. In all cases sugar does not destroy more than 2 per cent. of its weight of ferment.

Weak acids employed in small quantity assist fermentation; alkalies, on the contrary, stop it, or completely modify the reaction.

Ferment appears to be a kind of microscopic vegetation, which is spontaneously developed in the organs of plants, and in a large number of azotized substances left to putrefy. It is found in greatest abundance when a solution of sugar mixed with albuminous substances of animal or vegetable origin is exposed at the ordinary temperature. After some time the liquor becomes troubled, and deposits small ovoid bodies, which increase in size until they have attained the diameter of $\frac{1}{100}$th of a millimetre. Two different kinds of ferment may be distinguished, both by the manner in which they become developed, and by their mode of action upon saccharine solutions. The first or *upper yeast* is formed in a mixture of sugar, water, and albumen, at a temperature ranging between 64° and 77°; the second or *lower* yeast is formed only at temperatures between 32° and 46°. The form of these globules and their development may be studied under the microscope by diffusing a very small quantity of yeast in a little sweet-wort, and placing a drop of this liquor between two thin plates of glass, with a little mastic varnish at the edges to prevent the evaporation of the water. These plates are put under the microscope, and by carefully adjusting a single globule of yeast in the centre of one of the spaces formed by the cross threads of the micrometer, its development may be watched and measured. The accompanying figures show the arrangement of the new globules of yeast which are formed successively round the primitive globule A 1, at the temperature of about 66°. This first globule remains for about two hours unchanged; after which there is formed from a point of its surface a small swelling, which continues to enlarge during six hours until it has attained the dimensions of the first globule. See B 1, 2. This second globule produces a third, C 3, D 3, and so on, until after three days as many as thirty globules are formed round the first globule. On the fourth day there will be some increase, after which no more globules will be formed, the albuminous substances necessary to their formation being probably exhausted. Six successive generations of globules are in this way formed, and they are marked in the figures in the order of their production. The different globules appear to be in contact, but there does not seem to be any communication between them.

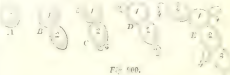

Fig. 900.

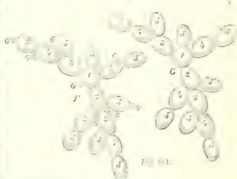

Fig. 901.

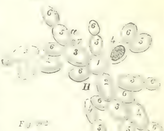

Fig. 902.

It appears from this experiment that when an albuminous substance is added to a mixture of sugar and yeast, the sugar is not the only substance acted on, for the albuminous matter undergoes several changes, and becomes converted into leaven. This explains how it is in breweries that when the fermentation of the worts is finished, a quantity of yeast is obtained seven or eight times greater than that employed to excite fermentation. This surplus yeast is to some extent used to excite the panary fermentation in bread. [See Bread.]

In the above microscopic examination it may readily be perceived that each globule is composed of a solid envelope enclosing a liquid; it forms a kind of cellule, the inner surface of which is coated with a mucilaginous substance. If the system of globules which has attained its state of complete development be examined during several days, it will be seen that a number of minute granules are formed in each globule; (see H 4;) the rapid motion of which shows that they float in a liquid. In the course of time this interior liquid is entirely transformed into granules.

The globules whose development we have been following belong to the upper yeast, and are formed by a system of buds one upon the other. The lower yeast is composed of isolated globules disseminated in the liquid: their formation may be observed under the same circumstances as in the upper yeast, but the temperature must not exceed 44° or 46°. Each globule appears at first as an isolated point in the liquid, and is developed until it has acquired a diameter of about $\frac{1}{100}$th of a millimetre. Some observers suppose that the original globules of the lower yeast burst and discharge into the liquid the granules enclosed within them, each of these granules then becoming a globule. The process, therefore, by which the lower yeast increases or *grows*, is quite different from that by which the upper yeast is developed. If the temperature be raised to 68° or 77°, the isolated globules of the lower yeast are immediately developed by buds, thus producing the upper yeast.

The action of the two kinds of yeast upon saccharine solutions is also different. The upper yeast produces a much more active fermentation, and a very abundant disengagement of carbonic acid, while the yeast is briskly agitated in the midst of the liquid, and foams up to the surface. The lower yeast acts much more slowly, often requiring two and three months to produce a complete transformation of the sugar into alcohol and carbonic acid; nor is the ferment in rapid motion in the liquid, or sent up to the surface; but it is deposited and accumulates quietly at the bottom. This lower yeast is employed on the continent in brewing that light description of bitter ale known as *Bavarian beer*.

Observers have not been able to trace under the microscope the changes which the yeast induces in a saccharine solution, the disengagement of carbonic acid rendering such observations difficult. It has been found, however, that the yeast increases about $\frac{1}{4}$ of its weight. Its chemical composition has also changed. Fresh yeast consists of—

Carbon	47.0
Hydrogen	6.6
Nitrogen	10.0
Oxygen, about	35.0

together with traces of sulphur, phosphorus, and some mineral bases, such as potash and lime. The same yeast after it has produced fermentation contains—

Carbon	47.6
Hydrogen	7.2
Nitrogen	5.0

so that while the carbon remains nearly the same as before, the hydrogen has sensibly increased, and the nitrogen has diminished one-half.

If an aqueous solution of iodine be brought into contact with the globules of ferment, the exterior envelope does not become coloured, but the interior liquid assumes a brown colour. This may be proved by breaking the globules between two pieces of glass. The envelopes present the characters of cellulose. When a certain quantity of yeast is left in contact with a saccharine solution, so as to be completely decomposed, and the residue be ground in a mortar, and the soluble parts removed by washing with water, alcohol, and ether, a white substance is left which yields glucose by the action of sulphuric acid, and does not dissolve in alkaline solutions, which, on the contrary, immediately effect the solution of the albuminous substances of the ferment.

Yeast dried in vacuo or at a low temperature is converted into a hard, horny, semi-transparent mass, of a reddish grey colour. Its property of determining the fermentation of saccharine solutions is not lost but only suspended, for on digesting it for some time in water it again becomes active. If it be boiled for a few moments it loses its characteristic property, but will regain it by exposure to the air, provided it has not been exposed too long to the temperature of 212°. Yeast also loses its fermenting property by being mixed with alcohol, sea salt, a great excess of sugar, oxide of mercury, corrosive sublimate, pyroligneous acid, sulphurous acid, nitrate of silver, the essential oils, &c. &c. This effect, however, is not produced by certain powerful poisons, such as arsenious acid and tartar emetic; and it is worthy of remark, that these substances do not interfere with the development of certain microscopic plants; solutions of emetic exposed for some time to the air become covered with confervæ.

Such is the amount of our knowledge on the subject of fermentation. Important as this process is in an industrial as well as a scientific point of view, that knowledge is very small. The action by which yeast or ferment determines the transformation of sugar into alcohol and carbonic acid still remains without explanation. Some chemists suppose that the development and the successive changes of the globules of ferment are determined by vital force; others suppose that the ferment acts by *catalysis* or mere *contact*, and that its action resembles that by which certain mineral substances effect the decomposition of weak combinations, without being themselves decomposed, or their elements entering into the reaction. It is thus that the binoxide of manganese determines the decomposition of the binoxide of hydrogen (oxygenated water) into oxygen and water, without being itself affected. So also chlorate of potash, which does not decompose under a temperature of 1,000° or 1,100° when heated alone, becomes decomposed at a greatly reduced temperature when intimately mixed with oxide of copper or binoxide of manganese, oxides which remain unchanged in the residue. Some writers suppose, that the motions of the particles of the ferment during their successive changes are the chief cause of the decomposition of the sugar, which motions being communicated to the saccharine particles destroy their inertia, and the elementary molecules group themselves in such a manner as to form more stable compounds.

In this article we have chiefly followed the abstract given by Regnault in the fourth volume of his "Cours de Chimie." A much fuller account of fermentation is given by Dumas in the sixth volume of his "Traité de Chimie." For practical examples of fermentation we refer to the articles BEER—BREAD—DISTILLATION—ACETIC ACID.

FERROCYANIC ACID. See PRUSSIAN BLUE.

FILE. A file may be defined as a strip or bar of steel, the surfaces of which are cut into fine points or teeth, which act by cutting, ploughing up, or abrading the substance to which they are applied. The surface operated on by the file is covered with minute irregular furrows, in consequence of the removal of particles of the material known as *file-dust;* but the state of the surface after the operation of filing depends on the size of the teeth of the file, the degree of accuracy with which they are cut, and the skill of the workman.

The varieties of files are almost endless, depending as they do upon the kind of work for which they are required. Thus files may vary in *length* from three-quarters of an inch, as in some of those used by the watchmaker, to 2 or 3 feet and upwards, as in some of those used by machinists and engineers. Watchmakers' files are of a more varied character than those of any other artisan, but they seldom exceed 4 or 5 inches in length; while the files used by the machinist are not under 8 inches in length. Mathematical instrument makers, gun makers, and those whose works are of medium size, employ files from about 4 to 14 inches in length. The length of files is measured exclusively of the tang or spike by which the file is fixed in its handle. There is no fixed proportion between the lengths and widths of files; but in general the lengths of square, round, and triangular files are from 20 to 30 times their widths taken at the widest parts; and the lengths of broad files, such as flat files, half-round files, &c., are from 10 to 12 times their greatest widths.

Files are also distinguished as, 1, *taper*, 2, *blunt*, and 3, *parallel.* The first kind are the most numerous, their length being made to taper so as to terminate nearly in a point. The second kind of files are made parallel, or nearly so, and hence terminating in a square or blunt end, are known as *blunt pointed,* or simply *blunt* files. In both kinds, however, the section of the file is largest towards the middle, so that the sides are somewhat arched or convex. A few files are made as nearly parallel as possible, and consequently have an equal section throughout; such are termed *parallel* files and *dead parallel* files; but even in these it is very common to find them slightly fuller in the middle. In almost all taper, blunt, and parallel files, the central line is kept as straight as possible; a very few files, such as the *rifflers,* used by sculptors and carvers, are made curvilinear in their central line.

Files are also distinguished as *Sheffield-made* and *Lancashire-made*, Sheffield, and Warrington in Lancashire, being the principal seats of the file manufacture in England. The Lancashire files are mostly the finer varieties, such as are used by watch and clock makers, mathematical instrument makers, &c. These files were formerly very superior to those made at Sheffield, in the quality of the steel, delicacy of form, perfection and fineness of the teeth, and success in hardening. Of late years the Sheffield manufacturers have gone on steadily improving, so much so that Mr. Holtzapffel thinks that in files exceeding 8 or 10 inches in length, Sheffield files are nearly equal to the Lancashire; but in files not exceeding that length the superiority is considered to pertain to the latter.

Files in other respects the same, may differ in the forms and sizes of their *teeth.* In the first place, files may be *double-cut;* that is, two series of straight chisel cuts are made to cross each other, whereby an immense number of points or teeth are raised on the surface of the file. In the second place, files may be *single-cut,* that is, a number of ridges are raised square across the file by means of one series of straight chisel cuts. Such files are distinguished by the name of *floats,* the term *file* always implying *double-cutting.* In the third place, when the surface of the steel is dotted over with separate teeth formed by the indentations of a pointed chisel or punch, a *rasp* is formed. Floats and rasps are used for woods and soft materials; double-cut files for metals and general purposes.

Double-cut files are further distinguished, by their respective makers, according to the fineness of the teeth, as follows:—

Lancashire files.	*Sheffield files.*
1. Rough.	1. Rough.
2.* Middle-cut.	2. Bastard.
3. Bastard.	3. Second-cut.
4.* Second-cut.	4. Smooth.
5. Smooth.	5.* Dead-smooth.
6. Superfine.	

The sizes marked * are not commonly made, so that we may consider that there are four degrees in each scale, the Lancashire being somewhat finer. All or any one of these four varieties of double-cutting apply to every length of file, so that the number of cuts in the inch varies greatly with the length of the file, as will be seen in the following table:—

LANCASHIRE CUT FILES

	4 in. long	6 in. long.	8 in. long	12 in. long	16 in. long	20 in. long
	Cuts ℘ in.	Cuts ℘ in.	Cuts ℘ in.	Cuts ℘ in.	Cuts ℘ in.	Cuts ℘ in.
Rough ...	56	52	44	40	28	21
Bastard ...	76	64	56	48	44	34
Smooth	112	88	72	72	64	56
Superfine	216	144	112	88	76	64

Floats and rasps are usually distinguished as *coarse* and *fine;* but these two varieties of teeth differ, in files, according as the length varies.

Some files, such as are used for making a set-off or shoulder, or in filing out rectangular corners, have one or more of their edges left uncut, or *safe* as they are called; such safe-edges rubbing against the work and guiding the cut part of the file, without acting on the part which they rub. In some cases the edges alone are cut, and the sides left safe or smooth.

With respect to the forms of files, their sections are derived from the *square*, the *circle*, and the *equilateral triangle*, as shown in the following figures.

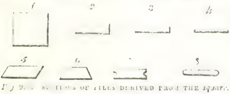

Fig. 963. SECTIONS OF FILES DERIVED FROM THE *square*.

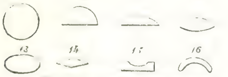

Fig. 964. SECTIONS DERIVED FROM THE *circle*.

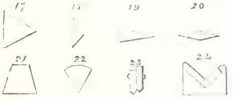

Fig. 965. SECTIONS DERIVED FROM THE *triangle*.

The names of some files are derived from their sections, as *square*, *round*, and *half-round* files; others from the uses to which they are applied, as *saw-files*, *slitting*, *warding*, and *cotter* files. But the files in most common use are those known as *taper* files, *hand* files, *cotter* and *pillar* files, *half-round*, *triangular*, *cross* and *round* files, *square*, *equalling*, *knife* and *slitting* files, and *rubbers*.

Taper files or *taper-flat* files vary in length from about 4 to 24 inches: they are rectangular in section, as in No. 2; they are considerably rounded on their edges, and somewhat also in their thickness; hence they are said to be *bellied*: all four varieties of cutting are applied to these files, which are in general use among smiths and mechanics.

Hand files or *flat* files resemble those last described, except that they are nearly parallel in width and less taper in thickness. They are commonly used for flat surfaces, and when more accuracy is required than in the work operated on by taper files; but in filing narrow apertures and notches, the taper file is used, first with the small end; next, the central and wider part; and then the whole length of the tool.

Cotter files vary from 6 to 22 inches in length: they are used in filing grooves for the *cotters*, keys or wedges, used in fixing wheels on their shafts; whence the name. They are narrower than hand files, and nearly flat on the sides and edges, so as to present almost the same section at every part of their length. *Taper cotter* files or *entering* files differ from the above: they taper in width and thickness, but have very little swell.

Pillar files, Section No. 3, are much narrower and somewhat thinner than hand files, and are used for lighter work, or for completing work that was begun with the hand file. They have usually one safe edge, and vary from 3 to 10 inches in length.

Half-round files, Section No. 11, are not, as the name would imply, semicircular in section, but the curvature may in general vary from the fourth to the twelfth part of the circle, the former being called *full* half-round, and the latter *flat* half-round files. Half-round files are usually taper: they vary from about 2 to 18 inches in length: the convex surface is used for various kinds of hollowed work, and the flat side for general purposes.

Triangular files, Section No. 17, also called *three-square* files, vary from 2 to 16 inches long: they are used for internal angles, for clearing out square corners and for sharpening saws.

Cross files, *crossing* files, or *double half-rounds*, Section No. 12, are circular on both faces, but of two different curvatures. They are used for filing out the *crosses* or arms of small wheels as in clock-work, the opposite sides of the tool presenting a choice of curvature.

Round files, No. 9, vary from 2 to 18 inches in length; they are usually taper, and are used for enlarging round holes: when small and taper they are termed *rat-tail* files, from the resemblance to a rat's tail; when small and parallel they are called *joint* files, from their use in filing the hollows in the joints of snuff-boxes, &c.

Square files vary from 2 to 18 inches long: they are mostly taper, and in some cases have one safe edge; they are used for small apertures, and for purposes to which the ordinary flat files are inapplicable on account of their larger size.

Equalling files, Section No. 4, are usually parallel in width and always parallel in thickness: they range from 2 to 10 inches long. In locksmiths' *ward*-files the two broad surfaces are left safe.

Knife files, Section 19, are usually made very acute on the edge, and from 2 to 7 inches long, both parallel and taper; they are used in cutting narrow notches, and in making the entry for saws and for files with broader edges; also in bevilling or chamfering the sides of narrow grooves.

Slitting files or *feather-edged* files are similar to the last, except that they have two thin edges instead of one, as in Section 20.

Rubbers are strong heavy files made of inferior steel from 12 to 18 inches in length, and from $\frac{3}{4}$ to 2 inches on each side: they are convex or fish-bellied, and are frequently designated by their weight, which may vary from 4lbs. to 15lbs. Their section is square and triangular, as in Nos. 1 and 17; or with one side rounded, such as would be formed by the union of Nos. 2 and 10, in which case they are termed *half-thick*. Their chief use is to brighten the surface of the work.

The small files used in watch making are numerous.

In the following enumeration of the Sections Nos. 1 to 24, the names of watch-makers' files are marked in italics.

Section No. 1. Square files, parallel and taper, some of which have one safe side: also square rubbers.

No. 2. Cotter files when large; *verge* and *pivot* files when small.

No. 3. Hand files, parallel and flat files: when small, *pottance* files; when narrow, pillar files; also taper flat files.

No. 4. When parallel, equalling, *clock-pinion*, and *endless-screw* files; when taper, slitting, entering, warding, and *barrel-hole* files.

Nos. 5 and 6. *French-pivot* and *shouldering* files, which are small and stout, and have safe-edges: when made large, and right and left, they are called parallel V-files, from their use in making the hollow VVs of machinery.

No. 7. Flat file with hollow edges, used as a nail file for the dressing case.

No. 8. Pointing mill-saw file, round-edge equalling file, and round-edge joint file; made parallel and taper.

No. 9. Round file, gulleting saw file; parallel and taper.

No. 10. Frame saw file for gullet teeth.

No. 11. Half-round file: *nicking* and *piercing* files; cabinet floats and rasps; all usually taper. *Round-off* files for rounding or pointing the teeth of wheels. These files have a pivot at the end opposite the tang.

No. 12. Cross files and double half-rounds.

No. 13. Oval files; oval gulleting files for large saws. *Oval-dial* file when small.

No. 14. *Balance-wheel* or *swing-wheel* files, the convex side cut, the angular sides safe.

No. 15. Swaged files for finishing brass mouldings.

No. 16. Sir John Robison's curvilinear file. The inventor states that, having found a difficulty in filing hollow surfaces, in consequence of the scratches which the irregular cutting of even the best half-round or round files leave in the work, it became a question whether the teeth of these files could not be made as perfect as in flat files, by cutting flat strips of rolled steel plate on one side, and then squeezing them into the desired curve by a screw-press and a block-tin or type-metal swage, and, in the case of a round file, by pressing the plate round a cylindrical mandrel. In testing this proposal, Messrs. Johnson and Cammel took a thin equalling file, cut on both faces, such as No. 3 or 4, softened and bent it and then re-hardened it, thereby producing a file with a convex and a concave surface, as in No. 16. With a plate of equal thickness the central part was found to bend more easily than the edges, thus making the curve irregular; but by making the blank thinner and more flexible at the edges, the bending was successful and the section became truly circular. These curved files are now regularly manufactured.

No. 17. Triangular, three-square, saw files, and rubbers cut on all the sides.

No. 18. Cant file used for filing the insides of spanners for hexagonal and octagonal nuts, or six or eight canted bolts and nuts, as they are called.

No. 19. When parallel, *flat dovetail*, *banking* and *watch-pinion* files; when taper, knife-edge files. When the wide edge is round and safe, moulding files and *clock-pinion* files.

No. 20. Screw-head files, feather-edged files, *clock and watch-slitting* files.

No. 21. Used in finishing small grooves and key-ways: it is also named a valve file from one of its applications.

No. 22. A compound of the triangular and half-round file: similar files are sometimes made with three rounded faces.

No. 23. Double or checkering files, used by cutlers, gun-makers, and others. These files are similar in their application to the double saws used for cutting the teeth of racks and combs. [See COMB, Fig. 599, page 419.]

No. 24. Double file formed by fixing two flat files together in a wooden stock, and used for filing black-lead pencils to a fine conical point. It was invented by Mr. Cooper under the name of the "Styloxynon."

In the manufacture of files, the steel must be of good quality and highly converted; for if too soft or unequal in texture, the file itself would soon be worn down instead of the surface upon which it is intended to operate; if, on the contrary, it be too hard, the teeth become brittle and chip off at every stroke. Smith's rubbers are forged square from the bars of blistered steel as they leave the converting furnace· smaller files are forged from bars or rods of various shapes and sizes, tilted or rolled as nearly as possible to the sections required. Files of the best quality are made from cast steel. The iron bearing the mark CCND makes excellent steel for files; but the finest clock and watch-makers' files are made from the hoop L or Dannemora iron.

In forging files coke is used as the fuel. The general arrangements for forging are similar to those described in the article CUTLERY, p. 480. The man called the *striker*, is furnished with a large double-handed hammer with a broad face at either end; but the hammer wielded by the *maker* is smaller and single-handed, somewhat conical in shape, the wider end

[illegible] FORGING FILES.

forming the face. Three-square and half-round files are forged in grooved bosses or dies fixed in the anvil. The rod of steel being raised to the proper heat, which ought not to exceed a *blood-red*, the end is hammered until it fills the die: the maker holds the die and strikes with the small hammer; the striker standing before the anvil deals powerful blows on the heated metal, the flat faces of the hammers covering a considerable portion of the surface of the blank file at each stroke, expanding and levelling it at one operation. When the blank has been forged to the proper length, the tang is also drawn out by cutting into the blank a little on both sides with a chisel, so as to form in many cases sharp square shoulders, and then drawing out the part so cut to form the tang. The maker's mark or monogram is then stamped on. Blanks for round files are formed in a slightly conical swage: blanks for flat and square files are formed by hammering. The maker accustoms himself, as much as possible, to the forging of one description of file, in order that by the concentration of his skill and attention on one article he may attain perfection in its manufacture.

The forged blanks are carefully annealed, or *lighted*, in order to make the metal soft enough for cutting the teeth. Blanks for common files are softened in an ordinary annealing oven, but the best blanks are protected from the action of the air by being buried in sand contained in an iron box: this is slowly raised to the proper heat, which, as in the forging, ought not to exceed a blood red.

The surfaces of the blanks are next made accurate in form and clean in surface by *stripping* or *grinding*. The former process consists in smoothing the surface of the blank with a hard file, first across and then lengthways. this is the method adopted in Warrington, where most of the files manufactured are small. In Sheffield, all the blanks above a certain magnitude are ground on huge grindstones, as the more expeditious method. In a few cases, as in *dead parallel* files, the blanks are planed in the planing machine. The blanks are slightly greased preparatory to being cut.

A few years ago the Editor witnessed the operation of file-cutting at the establishment of Messrs. Beardshaw, Stevenson and Co. of Sheffield, who have recently permitted our artist to make sketches for the three engravings, Figs. 906, 907, and 913. Writing on this subject soon after his visit, the Editor remarked in the second volume of his work on the Useful Arts:[1]—"It is scarcely possible to examine attentively the teeth of a fine file, without being struck with their beauty and regularity; but how greatly is our admiration increased when we know that these teeth are cut singly with a hammer and chisel, the workman having no other guide than delicacy of touch and precision of eye, depending however rather upon the former sense than the latter. The cutting room is a long narrow apartment with a range of windows in front, opposite which are placed a number of low stone benches for the anvils, and seats for the workmen. The hammers weigh from one to six pounds each, according to the size of the file: they are curiously formed, the handle being so placed as to allow the mass of metal to be pulled towards the workman while making the blow. The chisels are formed of good tough steel, and also vary with the size of the file: they are somewhat broader than the file to be cut, and are sharpened to the proper angle: they are only just long enough to be held between the fingers and thumb somewhat as a pen is held, only in the left hand, the hollow of the hand being turned to the workman. But the peculiar method of handling the chisel depends in great measure on the kind of tooth to be cut. The file is held to its place on the anvil by means of a leather strap passing over each end of the file, and then under the feet of the workman in the manner of stirrups. At every blow of the hammer the chisel is made to cut a tooth, and the blows follow each other in rapid succession, the workman after every blow advancing the chisel forward by so slight a movement as to be scarcely perceptible. The chisel forms a number of angular grooves parallel to each other, the tooth being formed by the metal left between every two grooves. The skilful workman adjusts the weight of his blow to the kind of metal he is operating upon; and even in the same file, if one part be softer than another, he adapts the weight of his blow so that the teeth may be of the same size in every part. As the work proceeds he gradually shifts the file forward by loosening his tread upon the straps. When one surface is covered with single cuts, he proceeds, in double-cut files, to add a second row of teeth, making them cross the first at a certain angle, for which purpose the chisel requires to be held in a particular manner. When one side is covered, he proceeds in like manner to cut a second side; but as the teeth just finished would be injured by placing them on the naked anvil while hammering, they are protected by interposing a flat piece of an alloy of lead and tin, which completely preserves the side already formed. Small pieces of alloy with angular and rounded grooves are

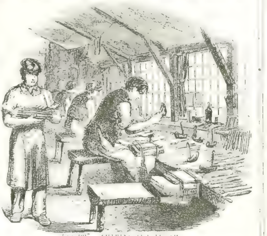
Fig. 907. CUTTING FILE TEETH.

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[1] Published under the direction of the Committee of General Literature and Education, appointed by the Society for Promoting Christian Knowledge.

used in cutting triangular and half-round files. Rasps, as already noticed, are cut with a triangular punch instead of a chisel, every new tooth being placed opposite a vacant space in the adjoining row of teeth. The curved surfaces of files show in a remarkable way the skill of the file-cutter: in them the teeth are formed with straight-edged chisels, many rows of short cuts being made from the top to the bottom of the file, and these cuts uniting together at their extremities thus form a complete series of lines, passing completely round the cylinder or half-cylinder as the case may be. In fine round files, as many as from ten to twenty rows of cuts are required to cover the surface with teeth; and when it is considered that there may be upwards of a hundred teeth within the space of an inch, some idea may be formed of the many thousand blows required to raise the teeth on a fine file. In double-cut files, when one row of teeth is completed, a fine file is run slightly over them, and the surface is greased to moderate the roughness before commencing the second row." In some of the double-cut gullet-tooth saw-files, Section 10, as many as 23 courses are sometimes used for the convex face, and only 2 courses for the flat one. The half-round and round files are usually cut by apprentice boys, the narrow cuts being less difficult than the broad ones. It might be supposed that all this labour might be saved by using chisels curved to the proper section, instead of straight ones; this plan has been tried and found to be quite impracticable.

The chisel used in cutting large rough Sheffield files is shown in Fig. 908. Its length is about 3 inches, the width $2\frac{1}{4}$ inches, and the angle of the edge about 50 degrees. The edge is straight, but one bevil is a little more inclined than the other: the edge is rounded off in order to indent rather than cut the steel. The hammer used with this chisel weighs about 7 or 8 lbs. Fig. 909, is the chisel used for cutting the small superfine Lancashire files: it is 2 inches long and ½ inch wide; very thin and sharpened at about the angle of 35 degrees; the edge is also slightly rounded: it is used with a hammer weighing one to two ounces. The largest files are cut by men: the smallest by women and girls.

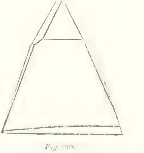

Fig. 908.

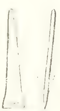

Fig. 909.

Mr. Holtzapffel describes the operation of cutting in the following terms:—"The first cut is made at the point of the file, the chisel is held in the left hand at a horizontal angle of about 55° with the central line of the file, as at a a, Fig. 910, and with a vertical inclination of about 12° to 14° from the perpendicular, as represented in Figs. 909, 911, supposing the tang of the file to be on the left-hand side. The blow of the hammer upon the chisel causes the latter to indent and slightly to drive forward the steel, thereby throwing up a trifling ridge or *burr;* the chisel is immediately replaced on the blank and slid from the operator, until it encounters the ridge previously thrown up, which arrests the chisel or prevents it from slipping further back, and thereby determines the succeeding position of the chisel. The heavier the blow, the greater the ridge, and the greater the distance from the preceding cut at which the chisel is arrested. The chisel having been placed in its second position, is again struck with the hammer, which is made to give the blows as nearly as possible of uniform strength; and the process is repeated with considerable rapidity and regularity, 60 to 80 cuts being made in one minute, until the entire length of the file has been cut with inclined, parallel, and equidistant ridges, which are collectively denominated the *first course.* So far as this one face is concerned, the file, if intended to be single-cut, would be then ready for hardening, and when greatly enlarged its section would be somewhat as in Fig. 911." Most files, however, are double-cut; that is, they have two series or *courses* of chisel-cuts. In cutting the second course, the chisel is inclined vertically as before, at about 12°, but only a few degrees horizontally, or about 5° to 10° from the rectangle, as at *b b*, Fig. 910. "The blows are now given a little less strongly, so as barely to penetrate to the bottom of the first cuts, and from the blows being lighter they throw up smaller burrs, consequently the second course of cuts is somewhat finer than the first. The two series, or courses, fill the surface of the file with teeth which are inclined towards the point of the file, and when highly magnified, much resemble in character the points of cutting tools generally, as seen in Fig. 911; for the burrs which are thrown up and constitute the tops of the teeth are slightly inclined above the general outline of the file, minute parts of the original surface of which still remain nearly in their first positions. Taper files require the teeth to be somewhat finer towards the point, to avoid the risk of the blank being weakened or broken in the act of its being cut, which might occur if as much force were

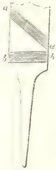

Fig. 910.

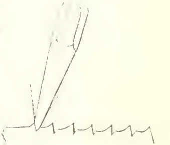

Fig. 911.

used in cutting the teeth at the point of the file, as in those at its central and stronger part."

The punch used in cutting the teeth of rasps is shown in Fig. 912. As seen in front, the two sides of the point meet at an angle of about 60°; seen in profile the edge forms an angle of about 50°, the one face being but slightly inclined to the body of the tool. Punches vary in size with the size of the rasp.

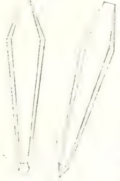
Fig. 912.

The punch in being used is sloped from the operator more than the chisel is in cutting files. By constant practice the workman hops the punch over the interval between two teeth with great rapidity and precision, producing a symmetrical arrangement of teeth with apparently very little effort. The left hand, which holds the punch, is protected by a piece of woollen cloth to prevent it from coming in contact with the steel. The directions of the teeth vary according to the purpose for which the rasp is intended. Thus, cabinet rasps, wood rasps, and farriers' rasps, are cut in lines sloping from the left down to the right-hand-side; boot and shoe last-makers' rasps are sloped the reverse way; gun-stockers' and saddle-tree makers' rasps are cut in circular lines. These variations are not of any importance, the only thing required being to make every tooth occupy a position intermediate between the two above it; because if the teeth followed each other in right lines, they would plough up the work and not reduce and smooth its surface.

The files and rasps are next hardened before they are fit for use. Some descriptions, however, such as are used upon wood, ivory, and other soft substances, are not hardened; such files admit of being sharpened up with a hand file. Some of the curved files used by sculptors and die-sinkers, are made of iron and case-hardened.

Before being hardened, the files are drawn through beer-grounds, yeast, or other adhesive fluid, and then through common salt mixed with roasted and pounded cow's hoof; the objects of which are, to protect the teeth from the direct action of the fire and the oxydizing influence of the air; to afford an index of temperature, the fusion of the salt showing when the hardening heat is attained; and to lessen the tendency of the files to crack on being immersed in water.

The files in the process of cutting become slightly curved, and it is necessary to straighten them before the hardening is completed. Some forms of file are apt to become curved in the act of hardening; such, for example, as the half-round file, which sometimes becomes hollow or bowed on the convex side; hence to produce a straight file it is purposely bowed, while soft, in the reverse direction. Most of the other forms of file are gradually heated to a dull red, and then straightened by striking them with a leaden hammer upon an anvil of the same material. A warped file is also in some cases straightened by being inserted between a couple of iron bars, fixed parallel a short distance apart, and then pressed in an opposite direction to the bend intended to be corrected. After the straightening, the file is placed in the fire again and heated until the salt fuses upon its surface; it is then immediately removed from the fire and plunged into a cistern of cold water. The method of plunging it into the water is of importance; it is held by the tang with a pair of tongs, and immersed quickly or slowly, vertically or obliquely, according to its form; that method being adopted which has been found by experience best calculated to keep the file straight. It is, however, very difficult to prevent some degree of set or curvature in quenching the files. Each file is therefore narrowly watched, and after being plunged once into the water, if any bending is observed, it can be remedied before the file is cold, by inserting it between the bars before mentioned, pressing upon it with considerable force, and ladling the water upon it with the hand: considerable curves may be corrected in this way. It is, however, in some cases necessary to re-heat the files, for which purpose they must not be placed in the forge-fire, or the teeth would be injured now that the smearing has been washed off; they are therefore held over a clear fire, or placed on a heated iron bar or over a hooded gas flame, and when straightened are quenched in oil to prevent the teeth from becoming rusty. After the hardening, the tang is tempered by immersing it in molten lead, for if the tang were left as hard as the file, it would be liable to snap off during use.

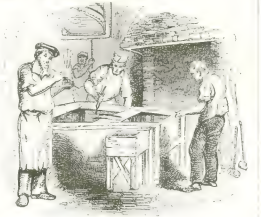
Fig. 913.—Hardening.

The files are next scoured with scrubbing brushes dipped into sand and water or coke dust and water; they are next put into lime-water, and left for some hours in order to get rid of every particle of salt. They are then thoroughly dried at the fire, rubbed over with olive oil containing a little turpentine, and are now considered as finished. Before packing them for sale, the foreman tests every file by striking it against a piece of steel, which is also rubbed against the teeth; and the quality and hardness of the file, and the regularity of the teeth are judged of by the vibratory sensations thus communicated to the hand. Imperfect files called *wasters* are sorted out and sold by the pound weight; the perfect files are wrapped up separately in papers, and made up into dozens.

The cutting of files by machinery has engaged the attention of many mechanical inventors. In the second volume of the Transactions of the American Philosophical Society, a file-cutting machine is described, in which the file is fixed on a bed of lead, and a chisel fixed at the end of a lever is struck down with a hammer. This lever rises again of itself by means of a spring, and during its rise it moves a ratchet-wheel connected with the support of the bed, which is thus shifted together with the file after every stroke. In noticing this machine, Mr. Nicholson offers some very sensible observations, which mechanical inventors would do well to study; and, as they are as applicable now as in the year 1798, when they were written, we venture to quote them here. He says:—"We will suppose a very acute theorist, who is not himself a workman, nor in the habit of superintending the practical execution of machinery, to have conceived the notion of some new combination of the mechanical powers, to produce a determinate effect, and, for the sake of perspicuity, let us take the example of a machine to cut files. His first conception will be very simple or abstracted. He knows that the notches in a file are cut with a chisel driven by the blow of a hammer, by a man whose hands are employed in applying those instruments, while his foot is exerted in holding the file on an anvil by means of a strap. Hence he concludes that it must be a very easy operation to fix the chisel in a machine, and cause it to rise and fall by a lever, while a tilting-hammer, of the proper size and figure, gives the blow. But, as his attention becomes fixed, other demands arise, and the subject expands before him. The file must be supported upon a bed, or mass of iron, of wood, of lead, or other material: it must be fixed either by screws, or wedges, or weights, or some other effectual and ready contrivance; and the file itself, or else the chisel, with its apparatus for striking, must be moved through equal determinate spaces during the interval between stroke and stroke, which may be done either by a ratchet-wheel, or other escapement, or by a screw. He must examine all these objects and his stock of means in detail; fix upon such methods as he conceives to be most deserving of preference; combine, organize, and arrange the whole in his mind, for which purpose solitude, darkness, and no small degree of mental effort will be required; and when this process is considerably advanced, he must have recourse to his drawing-board. Measured plans and sections will then show many things which his imagination before disregarded. New arrangements to be made, and unforeseen difficulties to be overcome, will infallibly present themselves. The first conception, or what the world calls the invention, required an infinitely small portion of the ability he must now exert. We will suppose, however, that he has completed his drawings: still he possesses the form of a machine only; but whether it shall answer his purpose depends on his knowledge of his materials. Stone, wood, brass, lead, iron, forged or cast, and steel in all its various modifications, are before him. The general processes of the workshop, by which firmness, truth, and accuracy are alone to be obtained, and those methods of treatment, chemical as well as mechanical, which the several articles demand,—these, and numberless other practical objects, call for that skill and attention which may either lead to success, or, by their deficiency, expose him to the ignorance or obstinacy of his workmen. If he should find his powers deficient under a prospect so arduous; if he cannot submit to the severe discipline of seeing his plans reversed, and his hopes repeatedly deferred; if unsuccessful experiment should produce anguish without affording instruction,—what will then remain for him to do? Will he embitter his life by directing his incessant efforts, his powers, and resources, to a fascinating object, in which his difficulties daily increase? or will he make that strong exertion of candour and fortitude which will lead him to abandon it at once?'"(1)

One of the earliest, if not the earliest, file-cutting machine is described in Thiout's "Traité de l'Horologie." Paris. 1740. In this machine the file is attached to a screw-slide, suspended at the end by pivots, and covered with a thin plate of tin. The slide rests upon a stationary anvil, and is worked by a guide-screw which is moved at intervals the space from tooth to tooth by means of a pin-wheel. The chisel is held by a jointed arm, beneath which is a spring to throw up the chisel from off the file the moment after a drop-hammer, also fixed on a joint, has indented the tooth. The machine is worked by a winch-handle, at every revolution of which the motions of the slide and hammer are repeated at proper intervals. It does not appear whether this machine was brought into practice; but towards the end of the last century another Frenchman named Raoul produced files by a machine, the details of which have not been published. A committee of the Lycée des Arts, appointed to inquire into the merits of Raoul's files, reported them to be equal, and even superior, to the best English files. In 1836, Captain Ericsson obtained a patent for file-cutting machines, which were constructed by Messrs. Braithwaites of London, and worked by Messrs. Turton and Sons of Sheffield. Mr. Holtzapffel says that "the details of these machines display great ingenuity and skill, especially in the arrangement for holding the blanks and the chisels, and also in the introduction of templets and other mechanism, by which, in cutting taper files, the hammer is less raised in cutting the ends of the file than at the middle, so as to proportion the force of the blow to the width and depth of the cut at different parts of the file Two machines were used for double-cut files, the bed of the one inclined to the right, of the other to the left, to give the different horizontal inclinations proper to these teeth; and a machine with a straight bed was used for single-cut floats and for round and half-round files. Considerable difficulty was at first experienced in the management of the chisels, which were then very frequently broken; but with more dexterous management it is ultimately considered that the chisels last for a longer time in the machines than when used by hand. The machines make about 240 strokes in the minute, or three times as many as the file-cutter, with the advantage of nearly incessant action, as, unlike the arm of the workman, the machines are unconscious of fatigue; moreover, to save the delay of adjustment, two beds for the files are employed, so that the one may be filled whilst the blanks in the other are being cut, and two frames for the chisels are also alternately used. Taking all these points into account, each machine is considered by the proprietors nearly to accomplish the work of ten men; but there are various drawbacks that prevent, under ordinary circumstances, any great commercial advantage in the machine over the hand process, from which considerations the patent file-cutting machines are not at present used." [1]

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(1) Journal of Natural Philosophy, vol. ii. 4to. 1799.

There is, however, one circumstance which will probably be most influential in overcoming all difficulties in the working of the file-cutting machine, and that is the rash and inconsiderate conduct of many of the file-cutters themselves. When the Editor was at Sheffield, he heard complaints from various quarters against the file-cutters; it was stated, that they were accustomed to draw money in advance, and spend it long before it was earned, in idleness and dissipation; that if the master refused to lend it, his name was "posted," and the men refused to work for him; that the file-cutters would work two, three, four, or five days in the week, and for as many hours in the day as suited their purpose, although the employer might be anxious to get an order executed; that if the masters attempted to coerce the men, violence was used, and in one establishment, gunpowder was introduced and fired by night, with a view to damage the property of the employer. Such statements as these are painful to hear, and still more painful to repeat; but he is the best friend of the operative who condemns such folly in the strongest terms, and points out to him its consequences, sooner or later inevitable. The shallow reasoning of the mob orator may persuade the file-cutters of Sheffield that files can only be cut at Sheffield, that they cannot be cut by machinery, and that the masters are tyrants who must be coerced. Now, there is no substantial objection why the file trade may not be removed from Sheffield, and files be cut by machinery. It is true that Sheffield has the converting furnaces and the well-exercised means of producing steel; but she does not produce the iron nor the fuel necessary for the purpose, so that this cannot be urged as a very powerful objection. As to the conduct of the masters, it is very possible that they do not always act with temper and discretion any more than the men: the masters seek their own interest in employing file-cutters; the file-cutters serve theirs in being employed. It is certain that the interest of the men depends upon that of their employers. It is not so certain that in this particular instance the interest of the masters depends upon the skill, steadiness, and obedience of the men; for if the men are wanting in these necessary qualities, capital will always find out and reward ingenious persons, whose inventions will sooner or later supersede skilled labour. The men may oppose the introduction of machinery, but their opposition will be feeble; the strong arm of the law will put down the one and protect the other, and file-cutting will then cease to be a manual operation. Should these few remarks (written by no unfriendly hand) fall under the notice of one of the Sheffield operatives, whose skill we both admire and respect, he is invited to receive them in the same spirit with which they are here offered.

A file-cutting machine was exhibited in the Russian department of the Great Exhibition. The display of hand-cut files in Class XXII. of the English department was a splendid one; but the collections of files exhibited by Austria, the Zollverein, and France, were also very conspicuous, and proved that the art receives great attention abroad. In the Danish department was a series of files manufactured of cast-steel by J. W. Naylor, of Copenhagen. The largest file (which was square, of Section No. 1) was covered with a series of file-cutters' cuts representing on one face the city of Copenhagen, on another face the operations of the forge and of file-cutting, &c. These effects were entirely produced by the file-cutter's chisel; the effect of colour and shading being given by the various angles of the teeth reflecting the light at different degrees of obliquity. The teeth of a large circular file were cut so as to represent, in a spiral going several times round the file, the maker's name, the date, wreaths of flowers, &c. This file was hollow, and contained within it a second hollow file, which in its turn contained ten others, all ornamented with wreaths, &c. The smallest file was not larger than a small needle. The Editor carefully examined all these files, and could not but admire the skill, dexterity, and even taste of the workman, showing also, as they did, the just and honest pride which he took in his art.

FILLIGREE, a style of delicate wire-work, used for ornamenting gold and silver, introduced by the Italians, who call it *filigrana*, a word compounded of *filum* a thread or wire, and *granum* a grain or bead: this is in allusion to the early practice of ornamenting the wire-work with small beads. Wire used for this purpose is seldom drawn round, but flat or angular.

The display of filigree work in the Great Exhibition was very wonderful for delicacy of workmanship and fantastic beauty. The chief exhibitors were from Sardinia, Turkey, the Ionian Islands, and Malta.

FILTER—FILTRATION. The command of an abundant supply of pure water is one of the prime necessaries of life, and one of the most important conditions of health. Persons who reside in the country can in general select their own source of supply; and although the water which they consume may in many cases be hard instead of soft, yet it is generally free from those contaminating influences which affect the sources of supply in a great city. The daily consumption of water in the metropolis amounts to nearly 82 million gallons,[1] a considerable portion of which is derived from the Thames, a river exposed to numerous causes of contamination from the circumstance of its being the recipient of the sewage and drainage of the metropolis, and of the refuse of gas-works and other chemical factories situated on its banks. The enormous traffic on its surface further adds to the injury, by keeping solid matters in a state of suspension. Even some of the rural districts situated up the stream, being, from their proximity to the metropolis, abundantly supplied with manure, increase the contamination, by discharging into the river a drainage-water so highly coloured with soluble organic matters as to impart to the river in times of flood a distinct tinge, known as the *flood tinge*. [See APPENDIX.]

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[1] Holtzapffel, "Mechanical Manipulation," vol. ii. In this excellent work, the chapter on FILES extends to nearly 100 pages 8vo, and contains much valuable information respecting the use of files, and on works executed therewith.

Where the water supply of a populous district is of bad quality, various methods are adopted for purifying it, either by the company which supplies it or by the consumer, the operations of the former being, of course, on a vastly greater scale than those of the latter. The most obvious methods of purifying water are by allowing it to repose in large reservoirs, in order that it may deposit its solid impurities before being distributed; or by passing it through a filter or strainer, the pores of which are smaller in diameter than the diameter of the smallest of the solid impurities which it is proposed to separate from the water by this method. This is a mechanical action merely, as all kinds of filtration must, in the ordinary sense of the term, be; for, although certain clays and loams, when used as filtering materials, appear to exert a chemical action, by removing organic and saline matter from solution, this property rapidly declines, and is therefore not applicable to the rapid filtration of water in reservoirs. The same remark applies to animal charcoal, which, when fresh burnt, has a powerful decolourising and deodorizing effect, but requires to be frequently renewed in order to maintain its influence. A third method of purifying water on the large scale is strictly chemical, and consists in the formation of an insoluble precipitate by the addition of alum or of caustic lime.

To discuss these and other methods of purifying water for domestic use will lead us into various details which may not appear to belong to the subject of this article; but the construction of filters and the process of filtration are intimately connected with such inquiries as the following, to which we are about to invite the reader's attention:—1. What is the original source of supply of river, spring, or well water? what is the origin of its impurities? how is hard water distinguished from soft? 2. What are the best means for purifying water on a large scale? 3. What are the best methods of purifying water on a small scale?

The water used for culinary, domestic, and industrial purposes is exclusively derived from the rain which falls upon the earth, whether the immediate source of the supply be the cistern, the well, the spring, or the river. Rain-water is usually so pure that the action of the most delicate chemical tests is required to detect any foreign substance in it; so that, if our cisterns were formed of proper materials, and the rain fell directly into them in sufficient quantity, no better water could be desired. But as the exposed surface of our cisterns is too small to collect rain-water in any quantity, it is usual to discharge into them, by means of gutters and shoots, the water which falls upon the roofs of houses; and, as these are covered with dust, insects, and other impurities collected during dry weather, the rain-water of our cisterns is thus contaminated in various ways. In some places the rain-water collected on the surfaces of extensive roofs and flats is made to pass through a bed of porous materials on its way to the cistern, and thus the solid impurities are strained and separated before the water is used by the public. Such is the case with the large cistern of the ducal palace at Venice.

Wells may be compared with cisterns; but the channels which discharge rain-water into them are not formed of masonry, brick, or metal, but of the rocks which exist immediately beneath the surface. These rocks may be porous, or may abound in minute fissures, through which the rain-water, sinking through the soil, finds a passage, and being divided into innumerable liquid threads, it dissolves and carries along with it a portion of whatever soluble matter it may meet with. Hence, the water obtained from wells is not rain-water, properly so called: it is usually as clear and limpid; but it contains nearly always certain substances in solution which differ according as the geological structure of the country differs. The same remark applies to springs: their water is rain-water, which, after having traversed strata of greater or less thickness, is sent up to the surface by the pressure of the water in the neighbouring hills or other elevations. [See ARTESIAN WELLS.] The nature and proportion of the impregnation to which spring-water is subjected depend also on the extent of its transit and the kind of rock traversed. The action of rain-water upon certain kinds of rock leads to the production of mineral springs; and if the water descends to a certain depth in the earth, its temperature will become so much raised by the internal heat, that, on re-appearing at the surface, it will be as a thermal spring.

Water companies.	Sources of supply.	Houses supplied.	Gallons per day.
New River	Lea, Chalk Springs, &c.	95,0[illegible]3	25,000,000
East London . . .	River Lea	70,000	16,000,000
Southwark and Vauxhall	Thames at Hampton .	41,529	10,331,122
Lambeth	,, at Thames Ditton	28,341	6,100,000
West Middlesex . .	,, at Hampton . .	25,7[illegible]2	6,8[illegible]5,[illegible]68
Chelsea	,, at Seething Wells	25,030	5,[illegible]25,000
Grand Junction . .	,, at Hampton . .	17,221	6,764,292
Kent	River Ravensbourne .	1[illegible],072	3,500,000
Hampstead	Ponds and Chalk Well	6,348	[illegible]
Plumstead and Woolwich	Chalk Well	3,000	550,000
	Totals	32[illegible],5[illegible]1	81,025,8[illegible]2

Every river conveys to the sea the waters of some principal source, and in its descent it gathers into its bosom the waters of numerous minor sources or tributaries. Hence the chemical composition of river-water forms a sort of mean between that of the waters of all the surrounding sources. In times of heavy rain, however, and in a water-shed of some extent, where rain falls more or less every day, the rain-water does not all filter through the earth: a portion of it flows on the surface of the ground, and down the slopes of hills, &c. with considerable rapidity. In such case it dissolves a far less quantity of mineral than it would do if it filtered through the earth, and retained for a considerable time in contact with the soluble matters of the strata. Hence it will readily be seen that river-water is more likely to be chemically pure than spring-water. Another circumstance which favours the purity of river-water, is its exposure to the air, whereby it loses that excess of carbonic acid which is present in spring-water, and so greatly assists the solution of carbonate of lime.

These remarks must, however, be taken with some limitation; for it would not be difficult to point to an arrangement of strata in which the wells and springs yield a comparatively pure water, while the neighbouring rivers are strongly impregnated with saline matter. It is, however, generally true that river-water is purer than spring or well-water. Nevertheless, the constant limpidity of spring-water and its uniform temperature are advantages in its favour when the source of supply is not far distant from the place of consumption, and would lead to its being always preferred, provided it were sufficiently abundant at all seasons to furnish the required supply. Most people prefer spring-water, and will not drink river-water, especially when the river is used as the means of carrying off the drainage of a city, although the amount of drainage may be too small to influence the composition of the water.

The advantage of greater chemical purity of river-water is counterbalanced by the absence of limpidity. The waters deposited by every shower of rain carry along with them in their precipitous course to the river various kinds of vegetable matter, earth, loam, clay, sand, and other detritus from the soil. The proportion of foreign matter thus held in suspension in the water during heavy rains and floods is different in different rivers. In the Seine the proportion rises sometimes to $\frac{1}{2000}$th; so that a person drinking three pints of unfiltered Seine water in one day, at the time of strong floods, would load his stomach with 13⅓ grains of earthy matter. What would be the effect of such a dose upon the health, if continued for some time, is a question which medical men do not appear to have settled. It has been contended that, because sheep and some other animals, before they drink the water of ponds, first make it muddy with their feet, it is a sanitary process in human beings to drink muddy water. Such is not the popular opinion, which strongly, and, we think, wisely inclines to pure limpid water.

The quantity of mineral dissolved by any given water determines the extent of its *hardness*, a quality which may be either *temporary* or *permanent*. Perfectly pure water consists of oxygen and hydrogen only, and as such is perfectly *soft*. Such water kept in contact with chalk (carbonate of lime), dissolves only a small portion of that substance, one gallon of water weighing 70,000 grains taking up only 2 grains of chalk. Such an impregnation would make the gallon of water slightly hard: it would be said to have 2 degrees of hardness. Some waters contain as much as 12, 16, or even 20 grains of carbonate of lime per gallon: in which case, the solvent is carbonic acid gas, which is found in greater or less abundance in all water in the natural state. By boiling the water, the gas is driven off, and the lime (with the exception of the 2 grains actually dissolved by the water), having nothing to hold it in solution, falls down as a solid precipitate. The hardness of such water is, therefore, only temporary, and may be cured by boiling. The eminent chemists appointed to inquire into the chemical quality of the water supplied to the metropolis, found that an artificially prepared hard water containing 13½ grains of carbonate of lime per gallon, decreased from 13.5 to 11.2 degrees of hardness by being heated in a kettle to the boiling point: boiling it for 5 minutes reduced the hardness to 6.3 degrees, for 15 minutes to 4.4 degrees, for 30 minutes to 2.6 degrees, and for 1 hour to 2.4 degrees. Thus it appears that the softening effect of boiling does not take place at once, although the greatest proportional effect is produced by the first 5 minutes' boiling. By an hour's boiling, the West Middlesex water fell from 14.6 to 5.5 degrees, and the New River water from 14.7 to 4.1 degrees. Other salts of lime, such as the sulphate, are generally dissolved in water without the intervention of carbonic acid gas, and therefore remain in solution after the water has been boiled, thus imparting *permanent* hardness.

The method of testing the hardness of these waters was by Dr. Clark's soap test. The carbonate of lime in water decomposes about 8.8 times its weight of white curd soap, and 10.7 of common yellow soap. The other salts of lime act injuriously upon soap in proportion to the lime contained in them, the soluble soap containing soda being converted into an insoluble and useless compound containing lime: thus the water is deprived of lime, or softened, at the expense of the soap. The lime in 100 gallons of Thames or of New River water thus occasions the destruction of about 34 ounces of soap, before any portion of it becomes available as a detergent. By adding measured quantities of a solution of soap to a known measure of the water to be examined, until the soap begins to give a lather with the water, or until soap bubbles appear on the surface on agitation, the proportion of earthy salt, or the degree of hardness of the water, may be ascertained.

In the water of the eight principal Metropolitan Water Companies, the hardness was found to be remarkably uniform, varying from 14° to 16°, a range not considerably exceeded at any period of the year.

During floods, however, the hardness of Thames water may fall to 8° or 9°. The shallow well-waters of London were found to vary from 32° to 80° of hardness.[1] [See APPENDIX.]

It is not our purpose to discuss in this article those cases where the supply of water is scanty. We suppose it to be abundant in all cases, but not pure. If charged with mechanical impurities collected during its passage to the river's bed, the most obvious method of purifying it is by filtration. In some cases, the water before its distribution is received into large depositing reservoirs, and left at rest for some hours or days in order to deposit its solid contents. This method, however, is imperfect. M. Leupold at Bordeaux found that after ten days of absolute repose the waters of the Garonne admitted into the reservoir in time of flood did not recover their usual degree of limpidity. At first the grosser particles were precipitated with great rapidity, but the finer ones remained suspended for a considerable time. In certain localities, and especially in certain seasons, water exposed to the open air for 8 or 10 days contracts a bad taste from the putrefaction of innumerable insects, which fall into it from the atmosphere, and also from the formation of vegetable matter on the surface.

When water is discoloured by clay, organic matter, and other substances more or less soluble, neither repose nor filtration will restore the limpidity. A remedy was proposed about the middle of the last century, which consisted in throwing into the water a small quantity of alum, the effect of which is to produce an almost immediate precipitation of the earthy matters held in suspension. M. Darcet found that the addition of 7½ grains of alum to 1 quart of the muddy water of the Nile made it perfectly limpid in the course of an hour. So small a quantity of alum would not be injurious, especially when it is considered that its efficacy consists in its being decomposed: the alumina of the salt falls down with the precipitate: a portion of the acid of the salt is also saturated by the carbonate or bicarbonate of lime contained in the water; and in passing into the state of an insoluble subsulphate or other compound, is precipitated, and in the act of falling drags down mechanically the earthy particles in suspension. The alum may be employed in powder or in the lump. In the latter case a large crystal is attached to the end of a line, and moved through the water in all directions near the surface; removing it as soon as bulky flocks appear, for the formation of this precipitate is a sign that a sufficient quantity of alum has been used. When powder is used, the proper proportion should be weighed out and sprinkled over the whole surface of the water, which must not be agitated. The alum may also be dissolved in a small quantity of water and sprinkled over the surface, then gently agitated and left to repose. This last is the most rapid method.

This method of purifying water is too refined to be trusted to any hands but those of a scientific chemist. It does not appear to be adapted to all waters, for certain minutely divided substances may escape the action of the alum, and remain suspended after the precipitate has been deposited. If the alumed water require subsequent filtration, then the use of alum appears to be a needless expense. Moreover, alum, however small in quantity, alters the chemical purity of the water by the introduction of a salt not naturally contained in it; and although this salt may be inert in certain proportions, it is easy to conceive that through the ignorance or carelessness of persons appointed to conduct the process, those proportions may be increased to an injurious extent. It is also an objection that the sulphuric acid of the alum, by converting the carbonate of lime of the water into sulphate, induces a hardness permanent in boiling.

The use of alum as a purifier has been revived in our own day. The Thames, like other rivers, becomes turbid in times of flood, acquiring a yellow *flood-tinge*, which is only very partially removed by sand-filtration. This discolouration appears to be due to the compound of clay and organic matter washed out by the Brent, from the extensive and highly manured field of the London Clay Formation, which it drains. This clay tinge resists the action of acids, and does not even fall down with carbonate of lime precipitated in the water. It can, however, be removed by alum, 7 grains of that salt to the gallon of water being sufficient in general to precipitate the clay completely, and to produce a perfect discolouration.

The use of caustic lime is less objectionable than alum, for the purpose of softening and purifying water by removing from it carbonate of lime, and a portion of the organic and colouring matter. Carbonate of lime is held in solution by the free carbonic acid gas dissolved in the water; by adding caustic lime, either in the form of lime-water, or of the dry hydrate, the carbonic acid immediately combines with the lime, converting it into insoluble chalk or carbonate of lime, which is precipitated together with the carbonate of lime originally held in solution. At the Mayfield Print-works in Lancashire, 300,000 gallons of water are thus purified every day, at a trifling expense and with little trouble. A careful series of experiments conducted by Messrs. Graham, Miller, and Hofmann, proved "that the means of conducting this process are certain in their results, and sufficiently simple to be left to the execution of a workman of ordinary intelligence. The precipitation of the carbonate of lime was terminated within 24 hours, and the water, if free from turbidity before the liming, continued in that state, but if originally turbid, it remained so, and required filtration besides the liming to make it clear. The New River and Thames waters were softened in this way to an average of about 3½ degrees of hardness, or to a lower point than by an hour's boiling."

This process was tried on a large scale at the Chelsea Water-works. The usual supply of water

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(1) Report by the Government Commission (Professors Graham, Miller, and Hofmann), on the Chemical Quality of the supply of water to the Metropolis. London, 1851.

pumped up from the river, was run into the first reservoir together with a small stream of milk of lime flowing from a wooden cistern. The intermingled streams passed on into one of the great settling reservoirs, to the extent of from 3,000,000 to 4,000,000 gallons, or nearly a day's supply. The quantity of lime was regulated by testing the water in the reservoir by a drop of nitrate of silver, which shows if the dose of lime has been exceeded by the formation of a brown-coloured precipitate. After subsiding for 24 hours or longer, the water was passed through the sand-filters and distributed. The degree of hardness in five such experiments, before and after the softening process, is stated in the following table, by Mr. J. Simpson, Jun. the resident engineer.

THAMES WATER AT THE CHELSEA WATER-WORKS.

1851		Degrees of Hardness.		Remarks.
		Before liming.	After liming.	
Feb.	21	14.0	4.5	The river was in good condition. The mixing was completed in 10 hours.
March	1	14.1	2.75	The river was in good condition. The mixing was completed in [illegible] hours.
...	15	14.7	5.0	The river was in flood, and the flood tinge was retained after liming.
...	22	11.6	4.5	Recovering from flood. The yellow flood tinge not removed.
April	17	15.5	3.6	The river in an average condition.

From these experiments, and from the success and simplicity of the liming process, the commissioners conclude that this process might be made to fall easily into the routine operations of water-works without being attended with any peculiar difficulty on the large scale. The softening of Thames water in its ordinary condition by this process, to a point under 4 degrees of hardness, appears to be perfectly practicable. The water of the experiment of the 17th of April was analyzed before and after the liming. The whole fixed constituents contained in one gallon of water were found to be reduced from 24.07 to 8.31 grains, and the organic matter from 2.50 to 1.60 grains: the quantity of lime-salt present, considering it all as carbonate, was reduced from 13.65 to 2.63 grains. The softened water was clear and bright, and had acquired neither odour nor taste from the process. The cost of the process is estimated at about 20*s.* for one million gallons, and if generally adopted would add about 4 per cent to the price charged to the consumers. It must, however, be remembered that the liming process, even when combined with filtration, does not remove the yellow flood-tinge of Thames water, nor the objectionable taste of vegetable which such water has at the times of flood.

We come next to notice the methods of filtering water on a large scale.[1] Filtration may be described as of two kinds, one which is effected by the *surface* of the filtering material, and the other in which the *mass* of the filtering material operates by the retention of the solid particles of matter. If we pour rain-water upon a paper filter, such as is used by the chemist, it will pass through freely for a certain time; but as the minute impurities contained in the water accumulate on the paper, they gradually close up its pores, the water passes through more and more slowly, until at length it is arrested altogether. So also, when a mass of sand is employed as a filtering material, the minute impurities suspended in the water are arrested at various depths, and at length entirely choke or fill up the pores of the sand, and the water ceases to pass through. Hence, in order that filtering may be successfully kept up, it is necessary to provide means for maintaining a constant porosity in the filtering material. The quality of the filtered water depends on the minuteness of the impurities to be separated, and on the diameters of the pores of the filtering material. If these pores are less than the smallest diameter of the solid impurities, they will be retained, and the water will pass through clear. If, on the contrary, the solid impurities be of smaller diameter than the pores, they will pass through with the water, and the filter will be worthless. The filtering material must also be of such a kind as not to communicate any impurity to the water, and not to alter in mechanical texture by prolonged use.

In filtering on a large scale,—for the supply of a city, for example,—the cost and durability of the filter are important considerations. On the great scale of nature, the rocks which filter the water as it falls upon the surface of the soil constitute a vast permanent filter, the durability of which arises from the great extent of superficial or subterranean surface concerned. It might at first view appear to be easy to imitate this natural operation, and pass the muddy water of a river through the porous rock or sand which forms its banks; but this is often a costly proceeding, on account of want of permanence of and artificial structure so contrived. Toulouse is supplied with water from the Garonne in this way, and it has cost upwards of 40,000*l.* at various times for supplying a city of only 50,000 inhabitants. The cause of failure in this and other instances arises from the fact already noticed, that, when water filters through sand, it deposits its solid impurities to a certain depth between the interstices of the sand, rendering it necessary from time to time to renew the filtering surface. Unless this be done, the bed becomes impermeable, or, at least, not sufficiently porous to afford an abundant and permanent supply of filtered water. This is illustrated by some experiments, conducted by Mr. Wicksteed. A sand filter which yielded at the rate of 10 the first week, yielded 9 the second week, 6 the third week, and only 2 the fourth week; so that a large *natural filter* (as this description of filter is called) may go on for some years yielding a good supply of water, and then gradually diminish its supply until it ceases altogether. Hence the construction of these so-called natural filters requires much caution on the part of the engineer; and it will always be difficult, if not impossible, to calculate beforehand the amount of water which a natural filter proposed to be erected will yield.

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[1] In this part of our subject we have been assisted by the First Report of the Commissioners of Inquiry into the state of large towns and populous districts, 1844. In the Appendix is a report on the Filtration of Water, by B. G. Sloper, Esq.

A second system of filtration on a large scale consists in the formation of extensive beds of sand, of great thickness, resting on beds of gravel, &c. At intervals of time, from ten to fourteen days, the water is run off, and the filth which had accumulated during filtration is scraped off with a certain thickness of the sand of the filtering bed. Once or twice a-year the whole of the sand removed is replaced. This method is costly, and not altogether satisfactory. The expense of filtration at the Chelsea Water-works, on this system, was estimated in 1840 by Mr. Simpson as follows:—

First cost, exclusive of land	£11 700
Annual cost of raising water on filtering bed	800
Annual cost of cleansing and renewal	800
5 per cent interest on outlay of capital	585
Annual cost, &c.	£2 185

The quantity of water filtered was originally stated to be 2,300,000 gallons daily. This was increased to 3,136,320 gallons, or 72 gallons per superficial foot of the filtering bed. The quality of the water is said to vary with the state of the bed. Immediately after the removal of the dirt and about one inch of sand at each cleansing, the pores may be said to be open. About two feet depth of water is then run on the filter, and as the filtration diminishes by the obstruction of the pores, the depth of water is increased to augment the pressure. The filth then accumulates on the surface of the filter, so that, before the water can be filtered, it must pass through this objectionable material.

Mr. John Graham, of the firm of Thomas Hoyle and Sons, stated in his evidence before the Committee the method of filtering the water of the muddy stream for the use of the bleach-works at Dukinfield. Arrangements were made for filtering 48,000 gallons per hour, or half a million gallons per day; this being the daily consumption in $10\frac{1}{2}$ hours. The water is first received into two reservoirs of subsidence, one about 4 feet and the other about 11 feet deep, having together about 2,000 yards of superficial surface. The water remains in these reservoirs from 1 to 2 days before it passes to the filters. These reservoirs are washed out once in 2 or 3 years, at an expense of from 3*l.* to 4*l.* for the two. There are two filters, one of which has an area of 1,056 square yards, and the other of 969 square yards. During some months of the year, the quantity of water passed through these filters every 24 hours exceeded 800,000 gallons. The impurities which collected on the surface of the filtering beds were removed more or less frequently, according to the state of the river and the quantity of water filtered: at some seasons the surface was cleaned only once in three months, at other times once a-week; the average being once a-fortnight. At each time of cleaning, the impure coating on the surface is removed, to the depth of half an inch, by means of scrapers similar to those used in removing the mud from the surface of macadamized roads. Two men can clean each filter in one day, at 2*s.* 6*d.* each man. The impure sand thus removed is carefully washed, and replaced on the filters once a-year. For this purpose the sand is thrown into a trough containing running water, which then discharges its contents into a cistern, where the sand subsides, while the impure water overflows at the extreme end of the cistern. This washing and replacing of the sand costs 40*l.* per annum. The original expense of two reservoirs and two filters was about 1,200*l.*, including everything connected with them, such as gravel, sand, valves, cisterns, &c. The total expense for settling and filtering half a million gallons of water per day was estimated at 156*l.* per annum.

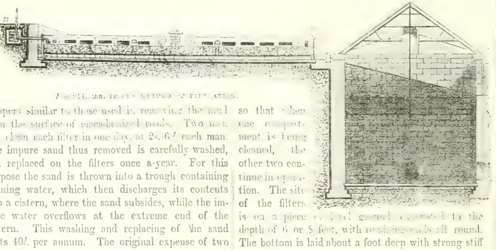

Fig. 914. MR. THOM'S METHOD OF FILTRATION.

A modification of this system, by Mr. Thom, has been introduced at Greenock, Paisley, and Ayr. Mr. Thom's self-cleaning filters were described by him in 1843 to the Commissioners for inquiring into the state of large towns. Fig. 914 will give some idea of the filter erected at Paisley. This filter is 100 feet long and 60 broad, and is divided into three compartments, which may be made to act together or separately, so that when one compartment is being cleaned, the other two continue in operation. The site of the filters is on a piece of level ground excavated to the depth of 6 or 8 feet, with retaining-walls all round. The bottom is laid about a foot deep with strong stiff puddle, over which pavement is laid, so as to be impervious to water. The walls are also joined with cement, and puddled behind, so as to be water-tight. The bottom is divided into drains, or spaces, 1 foot wide and 5 inches deep, by means of fire-brick laid on edge and covered with flat tiles of the same material, perforated with small holes, rather more than $\frac{1}{16}$th inch in diameter, and placed very near each other. There is also a space of $\frac{1}{4}$th inch left open between the ends of the bricks which support the perforated tiles, and their upper edges are little more than 1 inch broad, in order that there may be little or no space left without holes, and nothing to prevent the water spreading equally over every part of the bottom of these drains. This is particularly necessary when the filters are being cleaned by the upward motion of the water. The perforated tiles or plates are covered to the depth of an inch with clean gravel, about $\frac{5}{10}$ths inch diameter: upon this are placed five other layers of gravel, each of the same depth, and each succeeding layer a little finer than the preceding one, the last being coarse sand. Over this, to the depth of 2 feet, is placed very clean, sharp, fine sand, a little coarser than that used in hour-glasses: about 6 or 8 inches in depth of this fine sand is mixed with animal charcoal, ground to the size of coarse meal, each particle being about $\frac{1}{10}$th inch diameter. Water is admitted into the filter from collecting reservoirs or regulating basins by means of a stone pipe H and iron pipes R S P, connected therewith and with the top and bottom of the filters. Near the top of the iron pipe at S is a valve by means of which the water is made to enter at the top or at the bottom of the filter at pleasure. There is a longitudinal drain or pipe N between the filter and the pure-water basin, communicating with both; and on each of the openings between this pipe and the filter is a stop-cock, to close the communication when necessary. There are also two drains for carrying off the foul water when the filters are being cleaned, and another for preventing the water from rising too high in the filter. The action of the filter is as follows:—The sluice R and the valve S are opened, and the water permitted to flow through the filter into the drain N below until it becomes quite clear. When first set to work, this will take 2 or 3 days, unless the gravel and sand had been carefully washed before being put into the filter. Water will now flow copiously from the filter for some weeks, (the time being shorter or longer according as the water is more or less turbid on entering it,) and when the quantity begins to fail, the stop-cocks Z are closed, and the valves S raised. The water then enters *below*, and fills all the drains; and having a head pressure of several feet, it will force its way *up* through the sand to the top, and in its passage raise the scales or particles of mud which had been deposited in the downward passage, and carry them into the foul-water drain below. If the sand at the surface is stirred by a fine-toothed rake after the water has been raised above it, and a little additional water be admitted on the top, it will facilitate the operation of cleaning, as the mud is always deposited on the very surface of the sand. By this means the sediment will be carried off, and the water pass through quite clear again in a few hours: the valves at S should then be lowered, the stop-cocks at Z opened, and the operation of filtering proceeded with as before. The quantity of pure water produced regularly every 24 hours by this filter is said to average 106,632 cubic feet. The expense of such a filter to a town of 50,000 inhabitants is estimated at about 800*l*.

It is stated that, in practice, the simple return of the current of water upwards, even under a pressure of 26 feet, does not suffice to cleanse the filter, nor, in some cases, to remove even one-tenth of the dirt; that it requires violent agitation to dislodge and detach the filth from between the grains of sand. In cases where the supply of water was limited, the large quantity required for cleansing the filter would constitute a formidable objection to this plan, supposing it to be otherwise perfect. Another objection to these filtering-beds on a large scale is the great extent of ground which they occupy. The 15½ millions of gallons of water supplied daily by the New River Company would, if filtered on this plan, require upwards of 12 acres of ground for the filtering beds, slopes and intervals, engine-room, &c.

The filter invented by M. Maurras is free from some of the objections which apply to the filters already noticed. The filtering material is sand, of various degrees of fineness, and the arrangement will be understood by referring to Fig. 915, which repre-

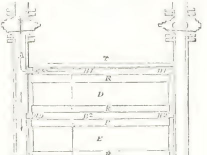

Fig. 915.

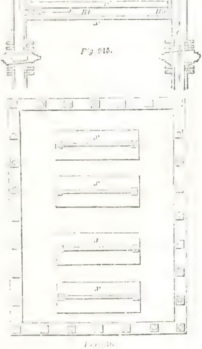

Fig. 916.

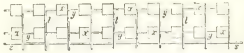

Fig. 917.

sents a section of a double-action filtering-machine, acting *per ascensum et descensum*. Fig. 916 shows the exterior of the case, which is made of iron, and water-tight, with the doors *x x* for the introduction of the sand. Fig. 917 is a plan of a double range of filters: *x x* are the filters, *y y* the supply pipes, *l l* eduction pipes of filtered water, and *s s* reservoir of filtered water. The entrance for the dirty water into the case is by the pipe A, Fig. 915; the exit for the filtered water, by the pipe C. The water in its passage through the box follows the direction of the arrows, and divides into two currents, one traversing the filtering-beds D of the coarser sand, E of the finer sand; the other current traversing the beds F of the coarser sand, G of the finer sand, meeting in the central chamber B^3, and passing off, filtered, by the cock H^3 and pipe C. B^1, B^2, B^3 are water-chambers communicating with the pipes A C by sluice-cocks at H^1—H^{10}; by means of which cocks the direction of the current of water may be varied at pleasure. The efficacy of this filter mainly depends on the simple manner in which the sand of the filtering-beds is retained, and prevented from escaping with the water under the pressure of the filtering water and the severe shocks which are required to detach and discharge the dirt from the filtering-beds. The filtering sand is retained by means of retaining-boxes R R. These are closed boxes, the upper and under surfaces of which are pierced with small holes of a certain diameter, which may be represented by 5, and filled and tightly packed with riddled sand of a diameter which may be called 6, and consequently incapable of passing through the small holes of the pierced plates of the retaining-box. Thus the sand in these boxes is a large-grained sand, easily retained; but the interstices between its grains are sufficiently small to retain the fine-grained sand of the filtering-beds. In this way the difficulty hitherto experienced of retaining fine sand is entirely overcome. The finest silver sand has been retained in an experiment of 3 months' filtration, under a pressure of a column of 60 feet of water. This method also admits of cleansing at intervals by the return of a current, and the shocks given by suddenly stopping it off, or meeting it by a reverse current having equal velocity. This is done by means of the sluice-cocks H^1—H^{10}, four of which being arranged to open and shut simultaneously, suddenly change the direction of the current, by which a violent agitation is produced between the pores of the filtering sand, and the dirt is dislodged and carried away. Hence it will be seen that the filtering material is sand of various degrees of fineness, so arranged that it cannot escape from its position in the machine; and, that the dirt is removed at intervals, and the porosity of the filtering sand restored. The machine represented in Fig. 915 is 5 feet 6 inches × 5 feet 6 inches, having a filtering surface of 60 superficial feet, capable of filtering 150,000 imperial gallons in 24 hours, with a head of water 12 feet 6 inches. According to some experiments made with one of these filters at the New River Head, Mr. Sloper estimates the cost of filtration in 24 hours daily at 2,600*l.* per annum, or 12 hours daily 4,000*l.* per annum; the delivery being 11,000,000 imperial gallons daily for 313 days of the year, the cost of filtration becomes by the first estimate 1*d.* for 5,500 gallons, by the second, 1*d.* for 3,600 gallons.

In coming now to notice the construction of small filters for domestic use, such a multitude of inventions and contrivances start up to view, that the difficulty is how to choose and where to begin. There are certain classes of subjects upon which the genius of inventors seems to run riot. *Filters* form one of these classes: *Fire-escapes* another. In either class, examples are as numerous as the attempts to solve the problem of perpetual motion, or to square the circle. Almost every kind of porous substance has been enlisted into the service of filters. The animal, the vegetable, and the mineral kingdoms have each contributed. Animal charcoal, sponge, and flannel; vegetable charcoal, cotton, straw, hemp, sawdust, shavings of wood, branches and leaves; various kinds of porous stone, sand, powdered glass, zinc and iron filings—are a few only of the filtering materials that have been used, and the methods of disposing them are as various as the substances themselves. It is necessary, however, to state at once, that in describing domestic filters, we shall scarcely notice those in which the filtering material is organic (except in the case of charcoal). It is true that filters of cotton, of wool, &c., have been tried for some time with apparent success, and have been favourably reported on by a commission appointed by a learned society. Their failure, however, arose from a cause which had not operated when the report of the commissioners was published. It was found that an animal or vegetable substance after being exposed for some weeks to constant moisture underwent decomposition, and imparted impurities of its own to the water which it was intended to purify and render potable. The wool-filter was made of mill-puff, which, being compressed, formed an excellent filtering material as far as minute porosity was concerned. It was used for filtering the water which supplies some of the fountains of Paris, to which the inhabitants resort for their usual supply; but after an extended trial, the defect which belongs to all organic substances as permanent filtering materials became too evident to be disregarded, and its use was discontinued.[1] Asbestus cloth has lately been proposed as a filtering material; and it is scarcely necessary to say that this is free from the objections which apply to flannel, cotton, &c. A mixture of charcoal and sand, or those substances arranged in alternate layers, is a favourite arrangement with filter-makers. The charcoal, however, is chemically as inert as the sand, and about as efficacious as a mechanical filtering material. In order for a charcoal filter to act chemically, a fresh supply of new-burnt animal charcoal ought to be used about every two days, a condition which evidently could not be complied with in a domestic filter, which, like ventilators and other salubrious contrivances, ought to be nearly, if not quite, self-acting, conferring positive benefits with very little trouble.

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[1] It is curious that this defect of organic substances used as filtering materials should have escaped the notice of that keen and accurate observer Reaumur. In 1745, M. Amy arranged sponge and other organic substances in vases, in alternate layers with sand; and in July 1749, Reaumur wrote the following certificate:—"J'en ai eu plusieurs, et à la fois, dont chacune avait été garnie par lui-même d'un filtre différent, les unes d'éponges, les autres de coton, les autres de laine, les autres de soie, et les autres de sable; elles ont toutes donné constamment une eau très claire et très limpide."

The Japanese and Egyptians appear from a very early period to have used vessels of sandstone, or of unglazed earthenware, for the purpose of filtering water. The stone was hollowed out into the form of a mortar, or was made egg-shaped, small projections being left at the top for resting upon a wooden frame, which supported it. Water being poured into this stone vessel, passed through with tolerable facility, and collecting at the point of the oval, fell into a vessel placed below to receive it. The solid impurities in the water being larger than the pores of the stone, were retained, and could be cleared out as often as it was found desirable. About the middle of the last century, a lias was found in Picardy, which acted as a very good filter. Stones of this kind were arranged so as to form a false bottom to a cistern, and the filtered water was drawn off by a stop-cock inserted in the space between the false bottom and the real bottom. One end of a vent-pipe entered this chamber, the other end passing above the cistern, thereby allowing the water to flow freely when the tap was turned.

In 1791, Mr. James Peacock patented a method for filtering by descent or ascent through sand and gravel. The apparatus consisted of a large supply-cistern placed at the proper height, below which was a closed box filled with washed sand and gravel, or with a mixture of charcoal and powdered calcareous stone. The water in the upper reservoir descended by a pipe into the bottom of the box, and the water was filtered by ascending through the strata of sand, &c., and was drawn off by a pipe fixed to the upper part of the box. The filter was occasionally cleaned by means of an exhausting and condensing pump, by which water was rapidly sucked up through the sand and gravel, and forced down again in the contrary direction, by which means the mud and dirt were first thoroughly stirred up, and then washed out of the filter.

In 1812, M. Paul of Geneva invented a filter consisting of a number of metal cylinders, each about 2 feet in length, and about 6 inches in diameter. From twelve to twenty cylinders are employed if necessary for one filter. They are filled to a certain depth with sand resting upon a diaphragm perforated with small holes. The water, which descends from the cistern or reservoir by a pipe, enters the first cylinder, passes through it by a pipe into the second, whence it ascends by another pipe into the third cylinder, and so on until it issues from the last cylinder perfectly filtered.

In 1814, M. Ducommon contrived a filter, composed, 1, of a solid base pierced with holes, for the purpose of supporting the filtering materials; upon this was placed, 2, a layer of sand too coarse to pass through the holes; 3, a second layer of sand of medium size, not sufficiently fine to pass between the interstices of the first layer; 4, a third layer of fine sand, or of pounded freestone, not sufficiently fine to pass through the medium sand; 5, a layer of fine charcoal about ¼ inch thick, if river-water is to be filtered; or a layer of coarse charcoal 10 or 12 inches thick, if foul water is to be filtered; 6, upon this is placed a layer of fine sand similar to No. 3, to keep the charcoal in its place, and protect it; then followed 7, a layer of coarser sand; 8, a still coarser layer similar to No. 2; and 9, a cover perforated with holes to prevent the stream of water from displacing the materials on entering the filter. A filter of this kind, of the sectional area of 40 square inches, was said to be capable of filtering from 110 to 115 gallons of water per hour. The precaution, however, was taken of first straining the water through a piece of canvass as it entered the filter.

In 1815, Count Réal obtained a filtering force by means of the pressure of a column of water, for which a force-pump was substituted by another inventor.

In 1819, M. Hoffmann of Leipsic employed condensed air as the filtering force. This was again improved on by Dr. Rommerhausen, who so arranged his filter, that the pressure of the atmosphere should take the place of the column of water, and of the condensed air. For this purpose the vessel containing the filtered liquid was connected with an exhausting-syringe or air-pump, so that the air could be extracted from it. Across this vessel the filtering materials were arranged in the form of a diaphragm, above which was another vessel containing the liquid to be filtered. It is evident that on rarefying the air in the lower vessel, the pressure of the air on the liquid in the upper vessel would act just as in the old air-pump experiment, in which mercury is forced through the pores of a piece of wood into a vessel contained within an exhausted receiver.

M. Fonvielle's filters also depend on the pressure of a column of water. The filtering materials are arranged in layers, and arrangements are made for cleansing them when required, by the simultaneous action of numerous currents of water, which, under a considerable head pressure, penetrate the mass of the filter in different directions, and from various heights, so that as the water flows in one direction from the filter, the mud and saline matters are removed, and by reversing the action of the stream, the water is perfectly pure and limpid, exciting the greatest surprise in the spectators. This plan is admitted to be founded on that of Mr. Thom already noticed.

In 1831, M. Lelogé contrived an ascending filter, consisting of four unequal parts, placed one above the other, the upper part, containing the water to be filtered, being equal in dimensions to the other three. The bottom of the filter is of solid stone or earthenware, just above which is an orifice, from which proceeds a tube up to the reservoir of water above. This lowest compartment is of small height; the water on entering it deposits its grosser impurities, which can, from time to time, be removed by a plug provided for the purpose. Above this are two reservoirs, the lower of which is separated from the one below and the one above it by flat perforated stones; this compartment is filled with charcoal; the second compartment is separated from the third by a filtering-stone. According to this arrangement, the water, on being poured into the top of the filter, is strained through a piece of sponge; it then passes down the tube into the bottom reservoir, where it deposits its coarsest impurities; after this, in consequence of the pressure exerted upon it by the liquid column, it filters *per ascensum* up into the third reservoir from the bottom, whence it may be drawn off for use. A filter of this kind exhibited at the Great Exhibition, is shown in Fig. 918, in which *c* is the channel for conducting the water W down into A; it then filters up through B into C, and may be drawn off at *t*. By opening the tap at *h*, the accumulated impurities may be cleaned out.

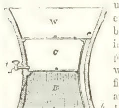


Fig. 918.

We have arranged these contrivances in chronological order, for the purpose of showing who really were the first inventors. Many new patents have been granted of late years for very old contrivances. Examples of domestic filters might be multiplied to almost any extent; but we will close this portion of our subject with a short notice of the filters shown in the Great Exhibition, most of which continued, during the six months that it was open, to supply the crowded assemblies with an abundance of bright sparkling water.

Of late years, that clean and beautiful material, slate, has been much used for water-cisterns. There were five exhibitors of such cisterns, some of which were of large size, and all were furnished with self-acting filters. The following figures show the arrangement of the filters exhibited by Mr. T. Sterling, sen.

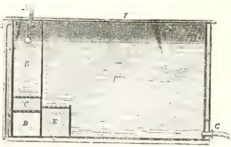
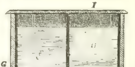


Fig.

Fig. 919 is a section of a large self-supplying filter. A is a pipe furnished with a ball-cock, through which the water to be filtered flows from the main, or other reservoir, into B, the foul-water compartment of the cistern, from which the water, passing down through the filtering media, C, D, and E, consisting of sand and vitrified limestone, rises into F, the pure-water compartment of the cistern, freed from its mechanical impurities. The filtered water is drawn off at G; pipes may also be attached to F, for supplying the kitchen boiler, and other parts of the house. H is a waste-pipe, to carry off the surplus water, in case the action of the ball-cock should be defective. I is a cover to the whole cistern. Fig. 920 is a section of the movable domestic filter, on the same principle, the same letters being used in both cases. It should also be stated, that some of these filters are so constructed as to allow of a hair-brush, such as is used for cleaning bottles, being introduced into a chamber at the bottom, when, by reversing the current of water, the bottom of the filter-bed may be cleared of mud in a few minutes.



F

Mr. Beart, of Godmanchester, exhibited an apparatus for cutting thin plates of sandstone, or other stone, and also a sandstone filter, containing 5,000 superficial inches of sawn surface.

An elegant little sandstone filter, acting by the pressure of a column of water, was exhibited in the main western avenue, so arranged as to form a fountain of filtered water. In the usual form of this filter, a hollow or porous stone filtering vessel, made in two or more parts cemented together, is placed in the cistern of water to be clarified. This stone is surrounded on all sides at a convenient distance with jackets of perforated zinc, galvanized iron, or wire-work. This jacket consists of two surfaces, the space between them being filled with animal charcoal. The stone vessel is provided with a tap and pipe for drawing off the filtered water. This arrangement is patented by Mr. W. Laird.

An ingenious form of filter was exhibited by the Wenham Lake Ice Company, the invention of Mr. Alfred Bird, consisting of a syphon, the extremity of the short limb of which is furnished with a box containing the filter, so that on inserting this into a cistern or water-butt, and withdrawing the air by applying the mouth to the

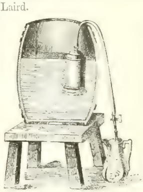


Fig. 921.

extremity of the longer limb, a stream of filtered water can be obtained, which may be arrested or set going by opening or closing a cock at the end.

Another ingenious filter, exhibited by Mr. Murray, consisted of a cock, such as is used for drawing off water from cisterns, with the filtering material packed into the cylindrical portion of the same. It is shown complete in Fig. 922, Fig. 923 being a longitudinal section thereof. It consists of a perforated metal tube, (copper is preferred,) covered with several layers of flannel *f f*, and calico *c c*. The ends of the perforated tube are inserted in metal rings *r r*, and the extremities of the calico are secured round the rings at *s s*, forming a water-tight fastening. The filtering medium is therefore flannel and calico, which, as before stated, is liable to the objections attaching to organic filtering materials: (if asbestos cloth were used, this invention would be perfect.) But as the present contrivance is ingenious, we will give Mr. Murray's description, as communicated by him to the *Mechanic's Magazine*. The metal rings are partly covered with a conical leather washer *l l*, which also ensures a water-tight joint between the dirty and the filtered water. This simple arrangement, enclosed in the outer case D D, forms the whole apparatus. The method of applying it consists in attaching it to the service-pipe *a*, between the cistern and the water-tap A; thus bringing the pressure of the column of water from the cistern into use. In Fig. 923 this outer case is shown in halves, the one being attached to the service-pipe *a* from the cistern, the other having a short service-pipe *e* fitted with the tap A. The filtering tubes are put into one half, and the other part is brought up and screwed on as at E, Fig. 922. The water, flowing in the direction of the arrow, percolates through the flannel and calico into the space *b b*, whence it is drawn off filtered by the lesser tap B; and the water for household purposes is drawn from the larger tap A after having rushed through the tube T, the filter being thereby cleansed from impurities every time water is drawn from the tap A.

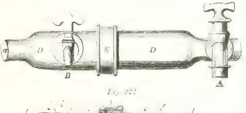


Fig. 922.

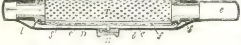


Fig. 923.

In is remarkable that very few filters were exhibited in the Foreign Department of the Great Exhibition. France contributed three; two of which were of stone, and one of charcoal. Sir W. T. Denison exhibited an excellent filter, made of a dripstone from Norfolk Island. The rock from which this stone was obtained appears to be a raised beach of calcareous grit. Such filters are much used in Van Diemen's Land.

In conclusion, we may remark, that in the laboratory, unsized paper is almost exclusively used as a filtering material. Other substances, such as flannel, tow, sand, pulverized glass, flints, porous stones, &c. may occasionally be used, but their use is exceptional. In the ninth section of Faraday's "Chemical Manipulation," ample directions respecting paper filters are given. Fig. 924 shows a common arrangement for filtering on a small scale, with filtering paper contained in and supported by a glass funnel. An arrangement is also made for retaining the liquid in the filter at the same height, until the whole of the liquor to be filtered is expended. For this purpose the liquor to be filtered is contained in a flask, inverted, with the neck dipping into the liquor already in the filter; as the liquor passes through and the neck of the flask becomes uncovered, a bubble or two of air enters, more liquor flows out until the neck becomes again covered, and all communication with the air is again cut off.

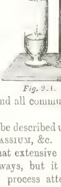


Fig. 924.

Special examples of filtering will be described under separate heads. See SUGAR—POTASSIUM, &c.

FIRE. This word is of somewhat extensive signification, and is used in various ways, but it commonly refers to an active natural process attended with the emission of heat and light, and also with the decomposition of certain substances which are said to be *burning*, or in a state of *combustion*, during the process, and are said to be *burnt* after the termination of the process. For the nature of the changes which take place we must refer to CARBON—HEAT—OXYGEN: and, for the various applications of fire, to the whole range of the useful arts; for without fire they could not exist, and without an instinctive knowledge of its use, man would scarcely be superior to the lower animals; in some respects he would be their inferior.

FIRE-ARMS, see GUN.

FIRE-DAMP, see COAL.

FIRE-ENGINE, FIRE-ESCAPE, and FIRE-PROOFING. See the next article.

FIRES, CASUALTIES BY, EXTINCTION AND PREVENTION OF. A large city, like London, containing 360,000 houses, is necessarily liable to many casualties from fire. In the construction of these houses much timber and other inflammable materials are used; the furniture is also, for the most part, capable of easy ignition: our system of warming leads to the use of a fire in many rooms, and often in every room of the house; our system of artificial illumination involves the use of gas, lamps, and candles; subservient to which are lucifer-matches, capable of easy, if not of spontaneous ignition; many shops have also considerable stores of spirit, turpentine, oil, fire-wood, and even of gunpowder; dangerous trades are permitted, or are not forbidden, in crowded districts; so that with these, and many other causes of danger, the safety of all the inmates of a house may depend, not only upon the care of each individual in it, but also upon the care of his neighbours. In the multifarious operations of a household, of a shop, or of a wareroom, in which fire is so largely concerned as a source of light, of warmth, or of heat, much vigilance is required to restrain within due bounds the operations of that wonderful agent which is truly described as "a good servant, but a bad master." During the day, when people are engaged in their accustomed duties, there is but little danger to be anticipated from fire; it is at night, when care and vigilance are slumbering, that the dread element, ceasing to serve and not expiring, often becomes the imperious master. There are probably few inhabitants of London who have not realized the startling effect of the cry of *fire* breaking in upon the silence of night. Taken up from mouth to mouth, we hear it in the distance in living echoes, accompanied by the quick tread of those who are hastening to the scene of danger and excitement. There is a momentary lull, in which neither cry nor tramp of feet is heard, but soon we perceive a sound like that of rolling thunder, becoming louder and louder every moment. We look out, and see the fire-engine swiftly passing by, drawn by horses at full gallop, heeding not the luckless passenger, and giving no quarter to other vehicles. Men, and horses, and vehicles, all yield to the fire-engine, which is soon beyond our sight and hearing. On proceeding into the street, the red glow of the sky immediately points out the direction of the fire: we join in the general excitement and hurry forward to the scene. A few minutes' quick walking will apparently bring us up to it; we hurry on, but reach it not; the red glow in the sky is stationary, but the streets between it and us seem to expand in length, and at every step to increase, instead of diminishing the distance: the red glow in the sky contrasts strangely with the pale yellow of the gas-lamps. "Where is the fire?" One says one place; another, another more distant; a third names a spot still more distant. But at length we near it. The streets are crowded with people, the road is wet with mud, the gutters are overflowing with water—a regular succession of dead, hollow, determined blows shows that the engine is being worked by willing arms—a jet of water rises up in a crystal line brilliantly illuminated by the flames which are streaming up out of the windows. With some exertion, and with feet drenched with thin mud, we get as near as we are allowed by the police, who are keeping a clear space for the engines and the firemen. We get near enough to feel the intensity of the heat, and to witness its effects in cracking the window-panes of the opposite houses, and blistering the paint on the doors. Every window, every roof, is alive with spectators; some of the neighbours are getting out their furniture; others are running about distracted; a third group are seated on the pavement, stricken with terror. Contradictory accounts are circulated respecting the origin of the fire and the present condition of the occupants of the devoted house. One report (probably the true one) is, that they are all safely housed with a neighbour; another report is, that three persons are missing. But the din increases: other engines having arrived, are now at work in front and in the rear. The war between the two elements is continued for an hour or more, till at length fire yields to water: the flames no longer discharge their rolling volumes of black smoke into the air, nor light up the sky with unaccustomed splendour. Dense volumes of steam arising from the evaporation of the water are the first signal that the fire is over; the multitude begins to break up, and soon the house on fire is nothing more than a wreck of blackened timbers and hollow walls.

The intense interest which a house on fire excites in the population of London, does not arise merely from curiosity and love of excitement. We believe, that in that vast concourse of people there is not an individual who would not work at the engines for hours without fee or reward, and although the fire-offices pay 1*s.* an hour for such labour, it is generally refused, or is expended in beer. Curiosity and love of excitement are doubtless great motors in bringing together this large assembly; but there are higher elements at work. A London fire is a grand and impressive spectacle, accompanied by a sufficient sense of danger to impart to it an excitement in which every one feels a personal interest; for the fire, which in this distant part of the town may have deprived a fellow-creature of his life, as it certainly has deprived several families of a home, and perhaps of the whole of their worldly goods, may some other night visit my neighbour's house or my own, and involve me and those who are dear to me in similar ruin. The motives, therefore, which excite this deep interest in a fire are of a very composite character: curiosity—love of excitement—feelings of humanity—interest in the safety and welfare of our fellow-creatures, no less than admiration of the skill and courage of that noble brigade whose business it is to be ready at any hour of the day or night with their own services, and the means placed at their disposal, for the extinction of fires in the metropolis and its vicinity.

That an organized staff of men, trained and accustomed to this duty, is required, will be evident from the statistics of the London fires. From the year 1832, when the London Fire Brigade was organized, a very accurate register of the metropolitan fires has been kept. The following extracts from the Register for the years 1833 to 1848 will show the kind of houses and occupations which are most exposed to casualties from fire:—

Apothecaries, and dealers in drugs	36
Bakers	244
Booksellers, Binders, and Stationers	137

Of these, 96 burnt gas, and the fires caused by gas amounted to 28.

Cabinet-makers	156
Carpenters and workers in wood	434

The accumulation of shavings, and their use in the stove, or in heating the glue-pot, account for the large proportion of fires in these trades.

Churches 33

Of this number 3 were totally destroyed, 10 much damaged, the remainder only slightly. 8 of these fires arose from stoves and over-heated flues; 2 from lightning.

Drapers, woollen and linen 254

239 of these burnt gas, and 140 cases arose from accidents with, or careless management of gas; 105 cases were very severe.

Fire Preventive Company 1

This arose from an experiment with a *fireproof plaster*, which took fire, burnt furiously, and caused much damage. Where was the scientific chemist which the Company did employ, or ought to have employed?

Firework-makers 49

Much damage was done in all these cases, which originated in the nature of the materials used in the trade; and these were in some cases ignited by the men smoking tobacco, by boys playing with fire, or from a squib or cracker being thrown into the shop-window "for a lark."

Gas-works 37

These are always supervised by scientific men, who adopt many precautions, and have means of prevention at hand: hence of these cases only 9 were much injured, and none totally destroyed.

Grocers 120

Of these, 109 burnt gas, and 26 of the fires arose from carelessness therewith.

Gunpowder-sellers 1

Knowing the danger, care is taken, and there is only 1 fire in 16 years.

Lodgings 868

Of these, 368 were caused by the taking fire of curtains, linen airing, &c.; some were caused by searching for vermin.

Lucifer-match makers 101

Lunatic Asylums 2

In the one case, familiarity with danger induces carelessness on the part of the operatives: in the other, persons who ought not to be trusted with fire are not trusted.

Printers and Engravers 72

Private houses 3,352

Of this number 1,302 originated in the taking fire of curtains, dresses, airing linen, &c.

Sale-shops and offices 526

Of these, 379 consumed gas; and the fires from this source were 129.

Ships 82

Caused by stores, flues, cooking, igniting of cargo, smoking tobacco, &c.

Stables 192

Caused by candles, lucifers, smoking tobacco, intoxication, &c.

Tailors 81

Of this number 17 were caused by gas, 13 by candles, and some by smoking tobacco.

Theatres 20

Of this number 8 arose from gas; others by smoking tobacco, and the taking fire of curtains, dresses, &c.

Tobacconists 43

6 of these fires were caused by gas; 6 by lucifer-matches; others by curtains catching fire; one was caused by a cat, and another by rats gnawing a box of lucifer-matches, which took fire under the friction of the teeth. A cat is not an unfrequent cause of fire, either by upsetting the clothes-horse with things airing, or, by creeping under the clothes to get nearer the fire, and so dragging some of them on her back into the kitchen fender.

Victuallers 542

Of this number 21 houses were totally destroyed; 167 much damaged, and 354 damaged slightly. 83 arose from flues; 73 from curtains, dresses, &c. taking fire; 65 from gas; 36 from smoking tobacco; 35 from accidents with a candle. The remainder arose from lucifers, hot cinders, a spark, intoxication, children playing with the fire, a monkey ditto.

The number of fires, and alarms of fire, that occurred during the fifteen years ending in 1847, present a continual increase. In 1833 they amounted to 458; in 1834, to 482; and so on down to 1847, when they amounted to 836. The total number of fires during the fifteen years was 9,662, making an average of 644. In 1848, the number of fires amounted to 805, showing in this case (which is an exceptional one) a decrease in the previous year of 31. In 1849 the number amounted to 838, being an increase of 33 over the previous year. In 1850 it was 868, being an increase of 30 over the previous year. This increase in the annual average number of fires, notwithstanding the efficiency of the Fire Brigade, must be referred to the rapid increase in the number of houses, and the increased use of gas and lucifer-matches.

The following tabulated statement respecting the fires of 1850 is copied from Mr. Baddeley's paper, in the *Mechanic's Magazine*, on the London Fires in 1850:[1]—

Months.	Number of Fires	Fatal Fires.	Lives lost	Chimneys on Fire.	False Alarms.
January .	80	2	2	10	10
February	79	0	0	5	6
March . .	84	2	2	12	9
April	69	3	3	5	10
May	[illegible]	2	2	2	2
June	72	3	4	4	4
July........	62	0	0	6	4
August ...	66	0	0	9	8
September	67	1	1	7	12
October ..	82	1	1	7	9
November	85	1	1	5	9
December	66	2	2	7	8
TOTAL	868	17	18	79	91

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[1] The Editor gladly takes this opportunity of bearing his testimony to the value of Mr. Baddeley's contributions to the *Mechanic's Magazine*, for many years past, on the subject of fires, their statistics, means of extinction, prevention, &c. It is no mean honour to be a competent authority on any subject; and Mr. Baddeley is such on this very important one.

Instances in which insurances were known to have been effected upon the building and its contents	381
On the building only	111
On the contents only	77
No insurance	269
	868
Alarms from chimneys on fire	79
False alarms	91
Making the total number of calls	1,038

Out of the 868 fires, 267 were extinguished by the prompt exertions of the inmates; 389 were extinguished by the inmates, with casual voluntary aid; while the suppression of 212 devolved on the firemen.

For recent statistics we must refer to the APPENDIX; but it may be here stated that the London fires of 1861 amounted to 1183.

A very interesting report on the fires in the metropolis, ordered by the House of Commons to be printed, 8th May, 1862, has been issued. The substance of it will be given in the APPENDIX.

The Fire Brigade is supported by the various Insurance Offices of the metropolis, whose interest it evidently is to afford the most powerful and efficient assistance, not only in all those cases in which they have undertaken to make good the damage to a certain insured amount, but in those houses also which are uninsured, for if these were neglected, they might involve the destruction of a whole neighbourhood, insured and uninsured alike. It should, however, be remarked that the firemen are entitled to the rewards of 30*s*., 20*s*., and 10*s*., for the first three engines that arrive, to be paid either by the owner of the house at which the accident happens or by the parish.

The Brigade is divided into 4 sections, with 19 stations, in the most central quarters of the metropolis, including two floating-engines on the Thames. The process of getting the Brigade into activity is described in a spirited article contained in the first volume of Dickens's *Household Words*, from which we gather a few particulars. When a fire breaks out, a policeman springs his rattle, and hurries off to the nearest fire-brigade station, giving information as he passes along to his comrades, one of whom proceeds to the fire-brigade station next beyond, while others fetch the fire-escape, which is provided in every parish by the "Royal Society for the Protection of Life from Fire." The fire-engine kept by the parish is also sent for. On arriving at the chief office, the policeman rings the night-bell, which is immediately answered by the fireman on duty for the night; he inquires after the locality, and a few short particulars respecting the fire; he then pulls a bell-handle, and applying his ear to the mouth-piece of a speaking-pipe, soon hears the voice of one who is accustomed to be disturbed at night; it is that of the superintendent, who answers from his bed, and on learning the particulars by means of the speaking-pipe, gives the necessary orders, immediately gets up, and in three minutes is descending the stairs attired in the thick cloth frock-coat, boots, and helmet of the Fire Brigade. The men below act with equal promptitude. No sooner is the superintendent roused than the watchman rings the foreman's bell, the engineer's bell, and the single men's bell, the latter to call up four unmarried men. He then runs to the stables, calls up the charioteer by the way, and 2 other firemen lodging close by, and then returns to assist in getting out the horses. By the time the superintendent has buttoned the last button he has arrived at the bottom of the stairs, and finds the engine ready and in working order, with its usual furniture, implements, and tools, placed within or packed about it, and of which the following is an inventory:—Short scaling-ladders made to fit into each other attached to the sides; 6 lengths of hose, branch pipes, director pipes, spare nozzle, suction pipes, a goose-neck for delivering water into the engine, iron wrenches called dog's-tails, a canvass sheet with rope handles round the edge for the purpose of catching people who are bold enough to jump out of the window, which they may do with perfect safety when the sheet is held by firemen; a dam-board for arresting the water and giving it depth, a portable cistern, strips of sheep-skin for mending bursting hose, balls of cord, a flat rose, an escape chain, escape ropes, a mattock, saw, shovel, poleaxe, boat-hook, an enormous crow-bar to burst in through doors or walls, or to break up the pavement, keys for opening fire-plugs or turning stop-cocks of the water mains. The superintendent mounts the engine to the right of the driver; the engineer, foreman and firemen mount also, and range themselves on each side of the long red chest at the top, which contains most of the articles above enumerated. Well acquainted with all the streets, and almost with all the houses of London, the superintendent directs the driver by the very shortest way, and having arrived at the scene of operation, he sees exactly all that has happened, all that must happen, that may happen, and all that may be prevented. The nature of the combustible, the direction of the wind, the age of the houses, the presence or absence of party walls; these and many other local particulars are rapidly generalized, a sound conclusion is at once arrived at, and a plan of operations decided on. Having ascertained that all the inmates are safe out, he orders 3 of the engines, which have now arrived from other parts, to continue their efforts; his own engine, and perhaps another, are driven round to the other side in order to attack the enemy front and rear. The water-plugs are drawn, the gutters flooded, the gully-hole is covered over, and a dam-board placed so as to arrest the stream, the portable cistern is filled, and the suction-pipes of the engine placed in it. Hundreds of volunteers are ready to work the engines: 20 pair of hands, 10 on each side, are required for each engine, and such is the ardour of the pumpers, and such the wasteful expenditure of useful muscular force, that the engine is frequently crippled before it has done 5 minutes work. Two firemen are sent into the house, no fireman ever being allowed to enter alone; two others enter below, and a lengthened hose is handed up to them with a boat-hook through the front drawing-room window, supposing the fire to have originated in the upper part of the house. A fireman ascends to the room where the inmates were last seen; it is full of smoke, but on dropping down and creeping along with his face almost touching the floor, he gets 10 or 12 inches of clear space, and air fit for respiration. Many a person who has fallen down fainting with the heat and suffocated by the smoke, is thus discovered and dragged out by the brave firemen, is handed to a comrade on the stairs, conveyed out into the open air and recovered. In this way, also, the fireman actually gets within 10 or 12 feet of the fire, and can direct the jet of water upon it, dashing it out, leaving a blackened, scorched mass behind and raising clouds of steam.[1]

The men are on the watch to see that the retreat is not cut off; a chain attached to the balcony of the drawing-room secures escape in case of need. All the efforts of the firemen are first directed to save life; this being done, furniture is secured; if the danger presses, the furniture is disregarded, however costly; all efforts are made to prevent the fire from extending to the adjoining houses. It is not till the molten lead is pouring down from the roof, and the ceilings are falling, that the men descend by the iron chain. Drenched and nearly exhausted, they are received by the superintendent and two men below, and are sent to change their clothes and get refreshment. At length the fire is subdued; a couple of men are left to watch the ruins, which are next day carefully examined by the superintendent, who is thus able, in many cases, to detect the cause of the fire, and to recover property buried under the ruins. What is remarkable in all these proceedings, is the smallness of the force employed. In a continental city, a regiment of soldiers would probably be employed in putting out a fire and preserving the peace: in London the whole affair is managed by a few policemen, a few firemen, a crowd of willing volunteers, and a multitude of spectators, most of whom would do their best to keep the peace and assist the efforts of the authorities.

Mr. Braidwood, in his work on Fire-Engines,[2] states that the operatives in certain trades make better firemen than in others; for example, he found that *slaters* make the best firemen, probably from their being accustomed to climbing and going along roofs; *house-carpenters* also make good firemen, from their acquaintance with the construction of buildings, which lead them to know where danger is to be apprehended, and, from the appearance of the house, where the staircase is situated, and how the house is divided; *plumbers* are also good, from being well accustomed to climbing, and are also useful in working fire-cocks, covering the eyes of drains with lead, and generally in the management of water; *smiths* are also to be recommended, as they can perform any repair about the engine, &c. Plumbers and smiths are also better able to bear the heat and the smoke than most other men; but the operatives in all the above-mentioned trades are better able than in most others to endure the extremities of heat and cold, wet and fatigue. If the men are selected between the ages of 17 and 25, they are more easily trained than older men.

We now come to consider the mechanical means which are adopted: *first*, for the extinction of fires; *secondly*, for the preservation of life and property during fires; and, *thirdly*, for the prevention of fires.

The FIRE ENGINE is undoubtedly the most efficient instrument which has hitherto been employed in the extinction of fires. Beckmann in his "History of Inventions," has a learned essay on the origin of this most useful engine. He shows, by quotations from the ancient writers, that the Romans had some contrivance termed *sypho*, for extinguishing fires, but no description thereof has been given. In the building-accounts of the city of Augsburg, bearing date about the year 1518, "instruments for fires," "water syringes, useful at fires," are mentioned. In 1657 Caspar Schott describes a fire engine at Nuremburg, which appears greatly to have resembled the modern engine. It was drawn by 2 horses on a sledge 10 feet long and 4 feet broad; the water cistern was 8 feet in length, 4 in height, and 2 in width; it was moved by 28 men, and forced a stream of water, an inch in diameter, to the height of 80 feet. Schott does not refer to it as a new invention, but states, that 40 years before, *i. e.* in 1617, he had seen a similar one, but much smaller, in his native city Königshofen. These engines were, however, very imperfect; "they had neither an air chamber nor buckets, and required a great many men to work them; they consisted merely of a sucking-pump and forcing-pump united, which projected the water only in spurts and with continual interruption. Such machines, on each movement of the lever, experience a stoppage, during which no water is thrown out, and, because the pipe is fixed, it cannot carry water to remote places, though it may reach a fire at no great distance, where there are doors and windows to afford it a passage. At the same time the workmen are exposed to danger from the falling of the houses on fire, and must remove from them to a greater distance. Hautsch, the maker of the above engine, had adapted to it a flexible pipe, which could be turned to any side as was necessary, but certainly not an air-chamber, otherwise Schott would have mentioned it. In the time of Belidor, there were no other engines in France, and the same kind alone were used in England in 1760. Professor Busch at least concludes so, from the account then given by Ferguson, who called Newsham's engine, which threw the water out in a continued stream, a new invention."

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[1] Mr. Baddeley remarks, that "the only successful mode of using a fire-engine, is to take the director or branch pipe into the building, as near as possible to the fire, and be sure that the stream of water strikes directly upon the burning materials. This cannot be too often or too anxiously inculcated on every person using a fire-engine. Every other method not having this for its fundamental principle, will, in nine cases out of ten, utterly fail. When the water is thrown into the building hap-hazard from the street, it is impossible to say if any of it touches the part on fire, or not, unless the flames appear at the windows." In order to economise the water, Mr Baddeley has invented a *spreader* to be attached to the jet, the object of which is, to throw the water in such a way that the entire surface of the burning part may be wetted and extinguished, and no more water used than is required.

[2] "On the Construction of Fire Engines and Apparatus; the Training of Firemen, and the Method of Proceeding in cases of Fire," by James Braidwood. Edinburgh, 1830.

The inventor of the air-chamber, the most important characteristic of a fire-engine, is not known. In a work published by Perrault in 1684, an engine belonging to the Royal Library at Paris is mentioned as consisting of only one cylinder, and yet throwing out water in one continued jet to a great height. In Germany, Leupold manufactured and sold a number of fire-engines furnished with air-chambers, the construction of which he kept secret for some time, but published an account thereof in 1720.

The invention of the leathern hose was also a great improvement; by means of this hose, which was capable of being lengthened or shortened at pleasure, water could be supplied to the engine from a distance, thus rendering the laborious conveyance of water by buckets unnecessary; the extremity of this pipe which dipped into the water, was furnished with a metal strainer pierced with holes to prevent the admission of dirt, and kept suspended above the mud by a piece of cork. By means of the hose the fire-pipe also could be properly adjusted. This invention belongs to two Dutchmen, named Van der Heide, who about 1670 were inspectors of the apparatus for extinguishing fires at Amsterdam. In 1690 they published a folio volume containing some valuable engravings, "the first seven of which represent dangerous conflagrations at which the old engines were used, but produced very little effect. One of them is the fire which took place in the Stadthouse of Amsterdam in the year 1652. The 12 following plates represent fires which were extinguished by the new engines, and exhibit at the same time the various ways in which the engines may be employed with advantage. According to an annexed calculation, the city of Amsterdam lost by 10 fires, when the old apparatus was in use, 1,024,130 florins, but in the following 5 years, after the introduction of the new engines, the loss occasioned by 40 fires amounted to only 18,355 florins, so that the yearly saving was 98 per cent."

The English were very slow in availing themselves of the discoveries of the German and Dutch engineers. At the close of the 16th century, *hand squirts* were in use for extinguishing fires; they were made of brass, of the capacity of from 2 to 4 quarts. A syringe capable of discharging two quarts of water, was about $2\frac{1}{2}$ feet long and $1\frac{1}{2}$ inch in diameter, that of the nozzle being half an inch. Every syringe required 3 men to work it; one man on each side grasped one of the two handles of the instrument with one hand and the nozzle with the other, while a third man worked the piston or plunger. In filling it the nozzle was immersed in water and the piston drawn out; the bearers then elevated it and directed the nozzle towards the fire, while the third man pushed in the plunger. Several of these instruments are still preserved in the vestry-room of St. Dionis Backchurch in Fenchurch-street, London. They were improved by being fixed in a portable cistern, and furnished with levers for working the piston; but in their best form they were inefficient contrivances, and had very little influence in checking the extensive fires which were so common at and previous to this time in large cities, when houses were built with abundance of timber, and instead of party walls, mere lath-and-plaster partitions, thus making a whole block of buildings like one house, and entailing the destruction of a whole neighbourhood by fire, instead of the single house in which the fire originated.

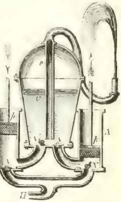

Fig. 925.

The principle of the fire-engine will be understood from the section, Fig. 925, in which H is the pipe or hose, which is extended by means of screw-joints to the plug or cistern, whence the supply of water is obtained. This pipe H communicates with two valves V V, which open into the pump barrels of two forcing-pumps A A, containing solid pistons *p p*. The piston-rods of these are connected with a working-beam, so arranged as to be worked by a number of persons on each side. From the sides of the pump-barrels above the valves V V, proceed force-pipes, which communicate with an air-chamber C by means of valves V′ V′ opening upwards into it. Through the top of the air-chamber passes a pipe *e* down nearly to the bottom. To the upper part of this pipe is attached the hose or jet used for directing a stream of water on the fire. This arrangement being understood, the action of the engine will be apparent. By the alternate motion of the pistons *p p*, water is drawn through the valves V V, and propelled through the forcing-valves V′ V′. Or to confine our attention for a moment to one of the pumps: on raising the piston *p* in the direction of the arrow, the valve V opens, water rushes into the cylinder A by the hose H, following the piston *p* as high as it ascends. On depressing this piston, the valve V closes, thus preventing the water from returning into H by way of V. As the water must escape somewhere from the downward force of the piston, it acts first upon the point of least resistance, which is the valve V′ opening upwards. The water forces this open, and rushes into the air-chamber C. The piston being then at the bottom of the cylinder, again commences its ascent, during which the valve V′ closes, the valve V opens, and water rushes into the cylinder as before. It is obvious, that as one piston is ascending while the other is descending, a continuous action is thus kept up, and water is always being forced into the air-chamber through one of the two valves V.′ Now it is evident that directly the water rises above the lower mouth of the pipe *e*, the air in the air-chamber is completely shut in, and just in proportion as the water accumulates, the enclosed air is compressed; the effect of this is, that the air in the air-chamber acts as a spring under constant compression. Its elastic force being exerted on the surface of the water, forces a column of water into the pipe *e*, and out through the hose and jet attached to it, with a force depending partly on the degree of condensation, and partly on the elevation of the extremity of the hose above the level of the engine. The pressure of the condensed air has *first* to support a column of water, whose height is equal to the level of the end of the tube above the level of the water in the air-chamber; and until the pressure of the condensed air exceeds what is necessary for this purpose, no water can spout from the end of the hose; and *secondly*, the force of the jet will be proportional to the excess of the pressure of the condensed air above the weight of the column of water, whose height is equal to the elevation of the end of the hose above the level of the water in the air-vessel. When the air in the air-chamber is condensed into half its bulk at atmospheric pressure, it will act upon the surface of the water with double the atmospheric pressure; while the water in the force-pipe being subject to only one atmospheric pressure, there will be an unresisted upward force equal to one atmosphere, which sustains the column of water in the tube. Consequently a column will be sustained or projected to the height of about 33 feet. When the air is reduced to one-third of its original bulk, the height of the jet will be 66 feet, and so on according to the proportions shown in the following table:—

Height of water in the air-vessel	Height of the compressed air	Ratio of the air's elasticity	Height to which the water is raised (feet)
$\frac{1}{2}$	$\frac{1}{2}$	2	33
$\frac{2}{3}$	$\frac{1}{3}$	3	66
$\frac{3}{4}$	$\frac{1}{4}$	4	99
$\frac{4}{5}$	$\frac{1}{5}$	5	132
$\frac{5}{6}$	$\frac{1}{6}$	6	165
$\frac{6}{7}$	$\frac{1}{7}$	7	198
$\frac{7}{8}$	$\frac{1}{8}$	8	231
$\frac{8}{9}$	$\frac{1}{9}$	9	264
$\frac{9}{10}$	$\frac{1}{10}$	10	297

Fire-engines on the above principle were constructed towards the close of the 17th century in France, Germany, and England. Newsham's engine was patented in England about this time, and continued in use to the year 1832, when the Insurance Offices of London, having combined in forming a general fire-engine establishment, adopted an improved form of engine. Newsham's engine consisted essentially of a strong oak cistern, about three times as long as it was broad, mounted upon four wheels. The pumps and air-vessel were enclosed in a case, from the top of which issued the jet-pipe. The suction-pipe was of strong leather, with a spiral piece of metal running throughout its length to prevent it from collapsing as soon as the air within it became rarefied by the first working of the pump. One extremity of this pipe was screwed to a nozzle at the lower end of the cistern, the other extremity being furnished with a strainer immersed in the water. In cases where the suction-pipe could not be used, water was poured by means of buckets into a wooden trough furnished with a strainer, from whence it passed into the cistern. A three-way cock, situated beneath the hinder trough, was turned according as the water was drawn through the suction-pipe, or was poured in by hand. The piston-rods were connected by chains to a double sector. There were two chains to each piston, one passing from the top of the sector to the lower end of the piston-rod, the other from the top of the piston-rod to the bottom of the sector; the chains were riveted to the sectors, and attached to the piston-rods by screw-nuts. Long handles connected with the sectors could be worked on each side. With such an engine, the water could be thrown in a continuous jet to the height of 60 or 70 feet, and with sufficient velocity to break windows. The engine was successful on its first introduction; it was purchased by the Government, by the nobility and gentry, by the different parishes, and by the insurance companies founded about this time, viz. the Hand-in-Hand, 1696; the Union, 1714; and the London Assurance Company, 1720.

In 1792 an improvement on Newsham's engine was patented by Mr. C. Simpson. In this engine the valves are contained in separate chambers instead of being placed within the cylinder and air-vessels, so that if a valve should fail, it was only necessary to unscrew and remove the covering-plate, when the valve could be got at without disturbing the other parts; whereas, in Newsham's engine, if one such valve became deranged, the whole engine had to be taken apart. Fig 926 is a sectional view of one of these engines made by Mr. W. J. Tilley of London, such as is recommended by Mr. Braidwood in his work on Fire-Engines. This engine is furnished with 6-inch barrels, and has a 7-inch stroke. The cistern A is of oak, the upper part B, and the side-boxes or pockets of Baltic fir. The sole, D, upon which the barrels stand, and which also contains the valves, is of cast-iron, with covers of the same material screwed down, and the joints made good with leather. At each end of the sole are brass pieces, E, in one of which is the suction-cock F, and to the other is attached the air-vessel G. This is of sheet copper joined at R, and attached to E by a screw. The exit-pipe H is attached to the under side of E by a swivel screw. The valves I are of brass, and ground true, so as to be water-tight. The barrels K are of cast-brass, and the bushes L of the same material. The engine is set on four grasshopper springs M. The hind axle is kneed at the cistern. The handles, *h*, of the levers P, are of lancewood. The box S is used for keeping wrenches, cord, &c. It has a false bottom, and the space T below it is used for keeping the materials necessary for a fire-escape, a chain ladder of 80 feet, a large canvas bag, and two strong belts. The hose is kept in the fore part of the cistern A and the box B. The directors and suction pipes are carried in the side-boxes or pockets. The rest of the tools required are arranged about the engine. There is also a bar for locking

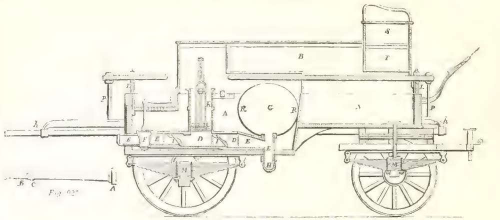

Fig. 927

Fig. 926. Section of Fire Engine.

the shafts to prevent them from interfering with the wheels when the engine turns. The director or jet-pipe, Fig. 927, is of copper, with a brass nozzle. The hollow screw at A is made to fit the coupling-joints of the hose. The joint B unscrews at C to allow the jet to be cleaned out. The interior should be polished to diminish the friction, and the orifice protected by being sunk a little within the metal.

The Steam Fire-Engine is an ingenious application by Mr. Braithwaite, of the moving power of steam to the working of fire-engines. The mechanical arrangement consists of two cylinders, the one 7 inches in diameter, which is the steam cylinder, and the other 6½ inches in diameter, which is the water-pump. Both cylinders are in a horizontal position, by which means the parallel motion is easily produced. The boiler is on the construction and principle of Braithwaite and Ericson's patent steam-generator. This engine will deliver about 9,000 gallons an hour to a height of 90 feet through an adjutage of ⅞ inch. The time of getting the machine into action from the moment of igniting the fuel is 18 minutes, the water being cold. As soon as an alarm is given, the fire is kindled, and the bellows attached to the engine are worked by hand. By the time the horses are harnessed in, the fuel is thoroughly ignited, and the bellows are then worked by the motion of the wheels of the engine, so that on arriving at the fire, the steam is ready. The expense of fuel is estimated at 6*d*. per hour. [See APPENDIX.]

In 1793, Mr. Joseph Bramah took out a patent for a fire-engine on the vibratory principle. [See PUMP.] This engine was defective in action. It was reproduced by Mr. Rowntree in the modified form, but not very successfully. Mr. John Barton, however, so far improved upon these attempts as to produce a tolerably good working engine, of which a section across one end is represented in Fig. 928. *a* is the cylinder or working-barrel of brass or iron; *b* is the fan or piston forming a radius of the circle, and composed entirely of metal on the expanding principle, with springs and segments as in Barton's metallic pistons. *c c c c* are 4 valves opening upwards; *d* is the air-vessel with the exit orifice at its lower part; *e* is the water-cistern; but this engine can also be supplied from a pond, &c., by means of a hose. "This engine is worked by the elevation and depression of the handles *h h*, connected with the axis of the fan *b*, which vibrates backwards and forwards in the upper part of the cylinder, and delivers at each stroke nearly one-half of its contents. The working of the fan or

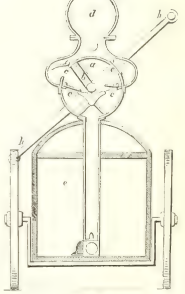

Fig. 928

piston *b* being air-tight, tends to produce a vacuum below on that side of the cylinder *a* where the handle is elevated, and the pressure of the atmosphere causes the water to rush up into this space. During this stroke, the air that occupied the other side of the cylinder has been partly expelled, and this space, on the second stroke being made, is filled with water, while that already on the other side of the piston is forced up into the air-vessel, and thence through the exit-pipes in a continuous jet."

A new form of engine was patented a few years ago, by Mr. White, of Salford. In this engine a number of small pumps, or working barrels, is substituted for the large cylinder. Each pump is worked independently of the others, and is constructed of a diameter to suit the power of a single man, so that if only one man is at hand at the commencement of a fire, he can immediately begin to work his portion of the engine, whereas, in working the ordinary form of engine, a considerable number of men is required. In the new engine it is stated that one man can throw water to a height of 160 feet. The pumps are mounted on a circular tank or reservoir, as in Fig 929, which is a horizontal section of a set of pumps:

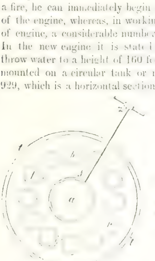

Fig. 929.

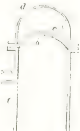

Fig. 930.

t is the tank from which the pumps are supplied; it is mounted upon wheels in the usual manner, for facility of transport. *p p* are the force pumps, 12 in number, each of which is worked by a separate lever *z*, moving upon a fulcrum at *f*; the air-vessel *a* is placed in the centre of the circle of pumps, all of which discharge their water into it. Above the air-vessel is a platform upon which the firemen stand. Fig. 930 is a vertical section of the air-vessel: *t* is the external vessel, on the top of which is a perforated plate *b*, over which is stretched a piece of vulcanized India rubber *c*; *d* is a hemispherical vessel forming a cover to the various parts, which are well bolted together. Within this last vessel the air is compressed to about two atmospheres, or 30 lbs. on the square inch, as the elastic resisting medium for the water to press against. By this contrivance the water does not come in contact with the air, and is thus prevented from passing off from the air-vessel with a crackling noise so often heard in the working of common fire-engines.

A trial was made with this engine at the Salford Gas-works, in December, 1845. The chimney of the works is 129 feet high; this was selected as the mark to show the height to which Mr. White's engine, and the *Deluge* engine belonging to the Town Council, could throw the water, each being worked by the same number of men. When White's engine was set to work with its full complement of 12 men, it threw the water for a short time several feet above the chimney; when the same number worked the Deluge they could not throw the water half that height, and even when 38 men were employed, they could not make the water reach the top of the chimney. Three lengths of hose pipe, about 120 feet in length, and with a five-eight nozzle, were then attached to each engine, and the result was equally in favour of Mr. White's engine.

Other forms of fire-engine might be noticed, such as Deane's portable engine and watering pump, in which the air-vessel surrounds the barrel of the pump. The centrifugal pump is also applied as a fire-engine; but we must refer the further consideration of these matters to the article PUMP, and the APPENDIX.

Mr. Phillips's *Fire annihilator* has excited considerable discussion. It is an apparatus arranged for generating a large quantity of gaseous matter, which will not support combustion. A house on fire is to have injected into it a sufficient volume of these non-supporting gases, to displace the air in the building, and to neutralize the effect of the strong currents of air which stream in on all sides upon the burning mass. The materials for generating the non-supporting gases are, equal parts of chlorate of potash, and sugar, ignited when required, by crushing a small glass vessel, containing sulphuric acid. The salt and the sugar, moulded into a homogeneous mass, are placed in a perforated cylinder, contained within a second perforated cylinder, which is contained in a third air-tight cylinder, and the whole is enclosed in an outer casing. Water is contained in the space between the bottom of the third cylinder and the outer casing; this is fitted with a vertical pipe opening into the space between the second and third cylinders, so that, as the metal expands by the application of the heat, water will be forced up the pipe, and mingling with the gas, will saturate it with moisture; the gas will then escape through an opening at the top of the case. We are not aware that this apparatus has ever been used in extinguishing an accidental fire; it has been used at several show fires with a considerable amount of success. It has been suggested that every house should be provided with a small fire annihilator; but, supposing its merits to be admitted, it would be necessary to supply the inmates of most houses with sufficient presence of mind to enable them to use this apparatus with effect; and having presence of mind, they might do without the annihilator; for, as Mr. Baddeley justly remarks, "of the 805 fires in the metropolis during 1848, no less than 577 were extinguished by the exercise of as much presence of mind as would be required to apply Mr. Phillips's apparatus."

Other plans for the extinction of fire might be noticed at considerable length, but our space will only allow us to refer to Sir William Congreve's plan, which has been in many cases adopted;—namely, to place large reservoirs of water on the top of a great building, from which pipes may descend to those parts most liable to fire, or which it is of the greatest importance to protect, so that the moment an accident occurs, the means are at hand for checking the flames. Thus, at the Royal Arsenal at Woolwich, there is a permanent reservoir of water 75 feet above the arsenal. The pressure of water from such a natural head produces jets of great power and effect in extinguishing flames.

It has been proposed to make the branch pipes, or a portion of them, proceeding from a reservoir of this kind, of fusible metal, so that, on the first breaking out of a fire, the pipes may melt and discharge water. This, however, would be of very little use, unless the fire happened to break out in so convenient a situation as to receive the jet of water directly upon it.

We may here also refer to Mr. Rutter's ingenious fire-alarum. An alarum apparatus is placed in the sleeping-room of the master, overseer, or watchman, and a galvanic battery in some other convenient apartment. A thermometer is also placed in every one of the apartments and passages of the house or building, and a double series of copper wires so laid throughout the premises, that on a given rise of any one of the thermometers, it shall immediately put the wires in communication with the battery and alarum apparatus, and so bring the latter into action. The thermometers are so constructed that metallic contact is formed, by means of platinum wires, with the separated parts of the copper wires leading from and to the battery, but in such a manner, that until the thermometers are acted on by a certain amount of heat, so as to cause the expansion of the air or other elastic substance within them, the current of electricity cannot pass from one part of the copper wire to the other; but as soon as this heat is applied, the mercury in the thermometers produces a continuous metallic circuit, and an electrical current will pass. In short, each thermometer, in its ordinary condition, interrupts the electrical current; and only in cases where great heat is produced near the instrument is the circuit closed, and the alarum apparatus set off. The alarum may be similar to that described under ELECTRIC TELEGRAPH, Fig. 817.

We come now to the second part of our subject, which leads us to notice a few of the innumerable contrivances invented for the purpose of saving life and property from fire. The most obvious forms of FIRE-ESCAPE are ladders. These are provided by many parishes in London, and are hung up horizontally under a wooden cover by the side of the church. They are made of different lengths, to reach a first, second, third, or fourth story. The largest kinds are sometimes furnished with guides, or hand rails, and also with contrivances for raising them; one of which is a short conical iron tube, jointed to one of the upper rounds of the ladder; a long pole fixes into this tube, and affords great facility in raising the ladder. Another form of ladder, already noticed, and to be recommended for its portability and convenience, consists of short lengths, 8 or 9 feet each, fitting into each other to any required length, by a strong simple joint, in the same way as scaling-ladders. In Gregory's ladders the two parts or lengths are made to slide one upon the other, and can be sustained at any required elevation: a cradle is attached for the rescue of timid or infirm persons. Wire chain ladders, and rope ladders with wooden steps, have been arranged in a variety of forms as fire-escapes. One of the most ingenious is Adam Young's. This is a rope ladder with wooden rounds, at the top of which is a hooked frame for catching into the window-sill. In order to raise these hooks up to the window-sill, the rounds fit together so as to form a pole, each round being formed with a projecting pin at one end, and a socket at the other; so that, by fitting the pin of one round into the socket of the previous round, the hooks are gradually raised until they catch the window sill, a single jerk or pull at the lower end then disconnects the staves from one another, and they fall into their places as rounds of the ladder, while at the same moment the rope sides become distended. Gregory's rope-ladder escape is supported on the window-sill or parapet by a hook composed of two sides, or arms, bent so as to resemble the external figure of the human ear, and hence called an *ear-hook:* the two sides are held together by three horizontal iron rails, the rope ladder is attached to the hook, and a sliding cradle is also arranged, the rope by which the cradle is worked passing over the central bar of the hook.

Among the simplest forms of portable fire-escape is a good strong rope, with a hook or loop at the end, by which it may be fastened to a bed-post, so as to enable an active person to descend, a partial footing being found in the inequalities of the wall. The descent is greatly facilitated by having the rope knotted at intervals of about a foot, the knots enabling the hand to grasp the rope securely. A common bed-cord is usually strong enough to support the weight of a stout man; a quarter-inch rope will readily support 2 cwt. or three times that quantity if new and good. By attaching a sack to the end, and passing the rope once or twice round a bed-post, women and children may be lowered into the street. In the Great Exhibition were two or three forms of fire-escape adapted to the bed-room; in one form a wire-rope was coiled up upon a drum contained within an ordinary dressing-table, a handle attached to the axis of the drum allowing the rope to be gradually let down or wound up. In another form a strong staple is attached to the window-sill for holding a pulley, the rope of which has a small wooden seat or cradle attached to it, so that a person might let himself down with a second person in his lap merely by holding the rope, and allowing it to pass with regulated speed through his hands. By the same apparatus he could also ascend to the bed-room in order to rescue another individual. When not in use, the pulley with its rope and cradle may be kept under the bed, or in the dressing-table. Many of the portable fire-escapes conveyed to, not kept in the burning house, have been useless on account of the difficulty of establishing a communication with the persons in danger. This, however, may be effected by means of rods 6 or 8 feet long, connected either by fishing-rod, or bayonet joints, or by screws. In Edinburgh the firemen use a cross-bow, and a three-ounce leaden bullet attached to a cord 130 feet long. The bullet and cord are thrown over the house by the cross-bow: to this cord a stronger one is attached, and drawn over the house by the former, and so on, until a chain ladder or escape is elevated.

Of the larger kinds of portable fire-escapes, the most efficient is the *carriage ladder*. In 1809 Mr. John Davies submitted to the Society of Arts a fire-escape consisting of 3 ladders connected to, and sliding upon each other by means of ropes worked by a small windlass. A second windlass raised and lowered a cradle supported by ropes passing over pulleys at the top of the uppermost ladder. This machine was mounted upon a low four-wheeled truck, drawn by a horse, or by 6 men. This escape was improved by Mr. Gregory, who used 3 ladders sliding on each other, which, when lowered, were balanced horizontally upon a convenient frame, mounted on a light four-wheeled carriage, so as to be capable of being run under low gateways, &c. The ladders being brought into the vertical position, or nearly so, are raised by a small windlass in front of the machine to any required height between 10 and 40 feet; the ladders are then inclined towards the window, upon the sill of which the top may be made to rest. A greater elevation than 40 feet may be obtained by means of joints, to be carried up and fixed at the top. A cradle is also used with this machine for the benefit of those who cannot descend ladders.

Our limits will not allow us to devote more space to the description of fire-escapes. We are conscious of having omitted many meritorious forms; but the reader who is desirous of studying the subject is referred to Mr. Baddeley's excellent article in Hebert's "Engineer's and Mechanic's Encyclopædia," vol. i. 1838, to the volumes of the Mechanic's Magazine since that date, and also, to the Transactions of the Society of Arts. People are generally indifferent to this subject until danger actually threatens; but it would be at least prudent that the occupant of every bed-room should ascertain what are the facilities for ascending to the roof, and passing to that of his neighbour. In detached houses internal means of escaping through the windows ought to be provided, but, as Mr. Baddeley remarks, "people rather choose to trust to the chance of obtaining external aid." If this should not be afforded in time, "egress can sometimes be made at the top of a house, either by a door, or by an opening made in the roof with a poker for the purpose. Sheets and blankets tied together, and fastened to the bed-post, or the bed-cords attached in the same way, afford the means of descending; the feather-bed, &c. thrown out, serve to break the fall when jumping from the window, as the last alternative. With a little contrivance women and children may be lowered by means of the bed-clothes. Upon these occasions all depends upon the persons in danger retaining so much presence of mind, as will enable them to avail themselves of the best means in their power: and it often happens that pressing danger develops a great deal more ingenuity and intrepidity in individuals, than they have previously taken credit for."

The third part of our subject relates to the prevention of fires. The methods proposed for accomplishing this desirable end are, to make houses fire-proof either by coating the timber with some substance which would render it less inflammable, or to reject combustible substances altogether in house building.

In 1775 Mr. Hartley's method of rendering houses fire proof, was encouraged both by a patent and a parliamentary grant. Thin iron plates were nailed to the top of the joists, the edges of the sides and ends being lapped over, folded close, and hammered together. It was proposed to protect partitions, stairs, and floors in the same manner. The plates were so thin as to allow the floor to be nailed to the joists in the usual manner, and to prevent the plates from rusting, they were varnished with oil and turpentine. This method did not survive its inventor, nor was it likely to have been very successful, for when it is considered that iron is a combustible requiring only a higher temperature than wood for its destruction, we cannot suppose that any great amount of security is to be obtained from thin iron plates covering massive timber framing.

The Earl of Stanhope, among his numerous mechanical contrivances, had a method of fire-proofing which consisted in the use of a non-combustible material, with, among, and between the timbers used in the frame-work of a house. His methods are described under the heads *under-flooring*, *extra lathing*, and *inter-securing*. Under flooring is either *single* or *double*. In single under flooring a common strong lath of oak, or fir, about ¼ inch thick, is nailed against each side of every joist, and of every main timber supporting the floor which is to be secured. Other similar laths are then to be nailed along the whole length of the joists, with their ends butting against each other. The top of each of these laths, or fillets, ought to be 1½ inch below the top of the joists, or timbers, against which they are nailed, so as to form a small ledge on either side of the joists. These fillets are to be well bedded in a rough plaster, so as to leave no interval between them and the joists, and the plaster is to be spread on the tops of all the fillets, and along the sides of that part of the joists between the top of the fillets and the upper edge of the joists. In order to fill up the intervals between the joists that support the floor, short pieces of common laths, whose length is equal to the width of these intervals, should be laid in the contrary direction to the joists, and close together in a row so as to be in contact; their ends must rest upon the fillets, and they ought to be well bedded in the rough plaster, but not fastened with nails. They must then be covered with one thick coat of the rough plaster, which is to be spread over them to the levels of the tops of the joists, and in a day or two this plaster should be trowelled over close to the side of the joists, without covering the tops of the joists with it.

In double-flooring the fillets and short pieces of laths are applied as above directed; but the coat of rough plaster ought to be little more than half as thick, and while being laid on, some more of the short pieces of laths must be placed in the intervals between the joists upon the first coat, and be dipped deep in it. They should be laid as close as possible to each other, and in the same direction with the first layer of short laths. Over this second layer of short laths must be spread another coat of rough plaster, which should be trowelled level with the tops of the joists without rising above them. The rough plaster may be made of coarse lime and hair, or chopped hay. One measure of common rough sand, 2 measures of slacked lime, and 3 of chopped hay, will make a good rough plaster. It should be made pretty stiff, and when the flooring boards are to be laid down soon, a fourth or fifth part of quick lime in powder should be added, which will cause it to dry quickly. When dry, should any cracks appear in the rough plaster near the joists, they are to be stopped with a mortar wash. Before the flooring boards are laid, a small quantity of dry sand should be strewed over the plaster work, and struck smooth with a hollow rule, moved in the direction of the joists, so that it may lie rounding between each pair of joists. The plaster work and sand should be quite dry before the boards are laid. The method of under-flooring may be applied to a wooden stair-case, but no sand is to be laid upon the rough plaster work. The method of extra-lathing may be applied to ceiling joists, to sloping roofs, and to wooden partitions.

The third method, inter-securing, is very similar to that of under-flooring; but no sand is to be laid on. This method applies to the same parts of a building as the method of extra lathing.

We notice these and some other methods without attaching much importance to them. Timbers coated with plaster, houses covered with fire-proof paint, soluble glass, and similar compositions, are not in many cases better calculated to resist fire than ordinary houses. If the house really contain a large quantity of goods and furniture, &c. of an inflammable kind, and the fire once obtain the mastery over them, we believe, notwithstanding the sham fire trials got up by the inventors of some of the fire-proof nostrums, that the house will share in the destruction of the goods. Indeed, we have had melancholy proof, that a house built of brick, iron, and stone, to the exclusion of timber, cannot by any means be said to be fire-proof, when the goods contained in it are inflammable. But we shall return to this subject presently.

A plan for the construction of floors and roofs has lately been advanced by Messrs. Fox and Barrett, who propose to substitute for the timber usually employed, joists of iron, and successive layers of incombustible materials, the floors being finished with a smooth and uniform surface, and the roofs with a coating of coal tar, paper and sand, the ordinary timber and slate roof being entirely superseded. The mode of finishing either the floors or the roof may, however, depend on circumstances, a surface of wood, straw, tile, cement, or other material, being readily adapted to the fire-proof foundation on which it is laid. The method of construction will be understood from Fig. 931, which represents in section one of the floors and ceilings. The joists J are of the T shape, reversed; they have a bearing of 6 inches on each wall, the ends being dove-tailed to form a sufficient tie. The strips which bear upon the flanges are generally formed of wood; but their ignition is said to be impossible, from the nature of the construction.

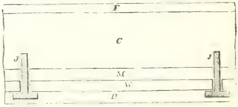

Fig. 931.

The coat of coarse mortar M is laid on about an inch thick, and forms a bed for the concrete C above, and together with the strips W, a key for the ceiling P below. The layer of concrete is about 5 inches thick, and may be formed of such materials as the locality of the building most readily supplies; road-grit, or clay from the foundation, mixed with a small portion of lime to bind it, answers well: gravel, burnt earth, clinkers, or broken brick, may also be used. The finished floor F is formed of a composition of lime and sand, well trowelled up to a face, and coated with linseed oil, which renders the surface hard, tough, and durable, and non-absorbent of moisture. The roofs are, for the most part, flat, and differ only from the floors in the method of finishing the surface. The ceilings are applied in the ordinary way, except that the usual ceiling laths are not required. The advantages of this plan are stated to be protection from fire, economy of construction, (the cost being said to be from 10 to 25 per cent. less than the ordinary method of flooring,) increased durability, security from the attacks of dry rot, and from insects and vermin.[1]

A plan proposed by Mr. Frost for the floors of rooms was, to use hollow earthenware tubes imbedded in cement, so combined as to cover the whole floor. The tubes are about 2 feet long, square in section, about $1\frac{1}{2}$ inch on the side, externally, with a tubular space of $1\frac{1}{4}$ inch on the side, internally. In forming a floor of these tubes, the centering, after being prepared and fixed in the usual manner, is first covered with a coating of cement sufficiently fine to form the ceiling of the apartment to be floored over, and if ornaments are required in this ceiling or its cornices, moulds for them are placed in the centering, so as to form a part of it. One or two coats of cement having then been laid over the centering, a stratum of square tubes laid side by side, and breaking joint, is imbedded in fine cement, and the interstices between them are filled in with that material. One thin coating of cement is then laid over the whole stratum; and in a week, when this is dry, another stratum of tubes is laid over the first in a contrary direction, bedded and filled in with cement as before, and finished with a coating of the same material. This, when dry, may have a second coating, to serve as the floor of an upper apartment, or the covering of the roof, as the case may be.

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(1) From a pamphlet published in 1849 by the inventors.

The following general directions, for the construction of fire-proof houses of small size, are given by Mr. Loudon, in his "Cyclopædia of Cottage, Farm, and Villa Architecture" (London, 1833–1842). The floors may be formed of flat tiles and cement, and covered with ornamental tiles; or flooring may be made of composition, and polished in imitation of scagliola or artificial marble. The roofs may be made flat, and covered with common cement, and the outer walls of the building may be tied together in all directions by wrought-iron rods made fast to stone bond, as broad as the wall is thick, the stones cramped or dovetailed together, and carried completely round the walls, about the level of the centre of each floor. The netting or lattice-work of iron rods connected with this chain of stone bond being thickly imbedded in cement, and cased with strata of flat tiles, would be kept from extremes of temperature throughout the year; so that the difference in their contraction and expansion during summer and winter would be of no practical importance. Every floor of a house thus formed would be in effect a single flagstone, and, as the iron rods would be prevented from oxidising, it would probably last for ages. It is easy to conceive the skeleton of an entire house thus constructed; the perpendicular supports being brick or stone piers, 3, 4, or 6 feet apart; the horizontal bonds on these supports of flagstone, of the width of the intended thickness of the walls or partitions, and all the horizontal floors or vertical panels of iron rods and wires covered on one or both sides with plain tiles coated with cement. Even the staircases might be so constructed and covered. In the case of the floors of rooms, square or nearly so, there might be circles of thin flat cast-iron laid on the horizontal rods, and made fast to them, which would serve as struts; and oblong rooms might have two or more cast-iron circles, or ovals, with plates of cast-iron in the direction of their short diameters, to serve the same purpose. The outer walls might have double panels of wrought-iron rods and wires, with intervals between, so as to form hollow walls; so that houses constructed in this manner might be rendered equally impermeable by cold or heat as those with thick walls, or with hollow walls of masonry. There would be no objection to houses of this description having all the doors and windows framed of timber, provided the panels and astragals were filled in with iron. As the iron rods and wires need not be of great diameter, (perhaps, in ordinary cases, of half an inch for the rods, and one-eighth of an inch for the wires, and half an inch in thickness with 3 inches in breadth for the cast-iron circles,) the expense even for the smallest house would not be an insuperable objection. Were the attention of the legislature turned to this subject, with the view of protecting those who at present cannot protect themselves,—we mean dwellers in town houses of the commoner kinds,—the Government would probably direct experiments to be made so as to bring this mode of construction, or some similar mode to a degree of perfection which would soon render it general.

Attempts have been made to render houses fire-proof without abolishing the use of timber in their construction. It has been proposed to make the timber itself indestructible by fire, for which purpose Mr. Payne, whose wood-preserving process is well known, has patented a method for rendering timber fire-proof by means of a solution of sulphuret of barium or calcium. The wood or other vegetable matter is put into an air-tight vessel, from which the air is driven out by means of steam: the steam is condensed by the injection of the solution of the sulphuret, and by the application of cold water to the outside of the vessel. A partial vacuum being thus obtained, the solution is allowed to flow into the vessel from the reservoir containing it through a pipe furnished with a stop-cock. The stop-cock is then closed, and an air-pump connected with the vessel is worked until as perfect a vacuum as possible is obtained within the vessel. The cock is again opened so as to allow the solution to fill the vessel nearly. It is then shut, and by means of a force-pump a further quantity of solution is introduced, until the pressure on the interior of the vessel amounts to from 110 to 140 lbs. on the square inch. This pressure is maintained for an hour, and the solution is then drawn off. The vegetable matter is next impregnated in a similar manner with an acid, or a solution of some substance, such as sulphate of iron, which will unite with the barium or calcium and set the sulphur free. When the vegetable matter is to be impregnated with a large quantity of solid matter, it should be dried between the application of the two solutions.

Without entering into any further details at present respecting the construction of fire-proof buildings, or stopping to point out the various methods in which iron joists and girders have been and are being extensively employed in large structures, we conclude by calling attention to a statement made about three years ago, by Mr. Braidwood, on the subject of fire-proof buildings, to the Institution of Civil Engineers. He exhibited a collection of specimens of cast-iron which had been used in the construction of buildings destroyed by fire, which showed that occasionally the temperature in the conflagration of large buildings rose almost to the melting-point of cast-iron. It was also stated that, even in a small fire, beams and columns of cast-iron would be so affected by the heat and jets of water upon them, that they would probably be destroyed, and sometimes cause great loss of life; as, in many of the so-called fire-proof warehouses of London, a number of persons employed on the premises slept in the upper floors, and if the lower beams gave way, the whole would be dragged down suddenly; whereas, timber beams resisted fire some time, and allowed time for the inmates to escape. The firemen, also, were liable to more danger from the same circumstance, as the only chance of extinguishing fires was to send them into the buildings with the branches and water-hose; but where the danger was so evident, the men were forbidden to enter, and their efforts were limited to preventing the fire from spreading. The expansion of the iron beams at high temperatures, and their sudden contraction on the application of cold water, caused a derangement of the brick-work: the mortar, also, frequently became completely pulverised by the excessive heat.

In the construction of fire-proof buildings, Mr. Fairbairn proposed, 1. That the whole of the buildings should be composed of incombustible materials, such as iron, stone, or brick. 2. That every opening or crevice communicating with the external atmosphere be kept closed. 3. That an isolated stone or iron staircase be attached to every story, and be furnished with a line of water-pipes, communicating with the mains in the street. 4. That the different warehouses be divided by strong partition-walls, and that no more openings be made in them than are absolutely necessary. 5. That the iron columns, beams, and brick arches be of sufficient strength not only to support a continuous dead pressure, but also to resist the force of impact to which they are subject. 6. That, in order to prevent the columns from being melted, a current of cold air be introduced into the hollow of the columns from an arched tunnel under the floors.

Mr. Braidwood argued, that if the second principle could be enforced, a fire would go out of itself; but it was doubtful whether the object was not defeated by carelessness in leaving a door or window open just at the time when a fire occurred. The fifth condition does not allow for loss of strength in iron consequent on high temperature; and the sixth was held to be insufficient, as a specimen of $1\frac{1}{2}$ inch cast-iron pipe, on being heated in the centre, with both ends open, and a current of air passing through it, gave way, after an exposure of only four minutes in the fire, on one end being held in a vice, and the other pulled with slight force by the hand. It was recommended that iron should not be used, but groined brick arches, supported by pillars of the same material laid in cement. Warehouses should also be built of a more moderate size, and be completely separated from each other by strong party walls. [See APPENDIX.]

FIRES, LIGHTING OF. There is much philosophy in common things, as may be illustrated by the apparently simple operation of lighting a fire. In this process we take advantage of the easy combustibility of one material to produce combustion in a second material, which is not so readily ignited: and this in its turn acts upon a third material, which is still less easily ignited. The paper burns easily and quickly, and kindles the wood, which burns less easily, and this in its turn raises the coal to a sufficiently high temperature to burn. The laws which regulate the draught of a fire were considered in the article CHIMNEY; but we may here notice a method of lighting a fire recommended many years ago by Mr. Gill, in his "Technical Repository," and which certainly does appear to deserve the praise which he bestows upon it:—Fill the grate with fresh coals quite up to the upper bar but one; then lay on the wood in the usual manner, rather collected in a mass than scattered; over the wood place the cinders of the preceding day, piled as high as the grate will admit, and placed in rather large fragments, in order that the draught may be free: a bit or two of fresh coal may be added to the cinders when once they are lighted, but no small coal must be thrown on at first. When all is prepared, light the wood, when the cinders in a short time becoming thoroughly ignited, the gas rising from the coals below, which will now be affected by the heat, will take fire as it passes through them, leaving a very small portion of smoke to go up the chimney. One advantage of this mode of lighting is, that small coal is better suited to the purpose than large, except a few pieces in front, to keep the small from falling out of the grate. It is stated that a fire lighted in this way will burn all day without anything being done to it. When apparently quite out, it will glow up on being stirred. When the upper part begins to cake, it must be stirred, but the lower must not be touched. Mr. Gill says that, on trying this plan with a common Bath stove, about 14 inches wide at the top, a fire lighted at 8 A.M. continued burning until 5 P.M. without being touched. The apertures at the bottom of the grate must be kept closed, either by the dust and ashes of the former day's fire, or by means of the small coal-dust contained in the coal used for lighting the fire. In this case it will continue to burn with a smouldering heat for thirteen or fourteen hours, with so little consumption of fuel, that at the end of that time, on being stirred up, and air admitted, a lively fire is produced. Even when smouldering, the fire gives out a moderate degree of heat.

FISH-HOOKS. The manufacture of these little articles requires a considerable amount of skill, attention to the material, and the method of manipulation, which, being practised by the manufacturers of one district, and not by those of another, have made the one celebrated, the others inferior. Thus, the Limerick fish-hooks have long been esteemed by anglers for salmon and trout-fishing: they are made of cast-steel, forged square by nailers, with solid wedge-shaped pieces at the end of each, out of which the barbs are formed by filing. The shanks are then filed round, and, after being bent to the required curve, they are carefully hardened, and tempered by being placed upon a plate of iron and heated until a drop or two of tallow let fall upon the plate smokes or blazes: this points out the proper tempering heat, according to the quality of the steel employed.

The barbs of the English hooks are cut with a knife, instead of being filed out of the solid. Fig. 932 is an enlarged representation of one of the real Limerick hooks, the barb of which had been filed out of the solid from a piece of steel shaped like Fig. 933.

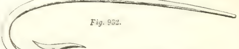

Fig. 932.

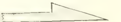

Fig. 933.

Sir Humphry Davy in his Salmonia describes the method of making the Limerick hooks. The first requisite is the softest and purest kind of malleable iron, such as is procured from the nails of old horse-shoes. This is converted into steel, and the steel into bars or wires of different thicknesses for different sized hooks, and then annealed. For the larger hooks, the bars must be made in such a form as to admit of cutting the barbs; and each piece which serves for two hooks, is larger at the ends, so that the bar appears in the form of a double-pointed spear, 3, 4, or 5 inches long: the bars for the finer hooks are somewhat flattened. The artist works with two files, one finer than the other, for giving the point and polishing the hook; and he begins by making the barb, taking care not to cut too deep, and filing on a piece of hard wood, such as box-wood, with a dent to receive the bar, made by the edge of the file. The barb being made, the shank is thinned and flattened, and the polishing file applied to it; and by a turn of the wrist round a circular pincers, the necessary degree of curvature is given to it. The hook is then cut from the bar, heated red-hot by being kept for a moment in a charcoal fire; then plunged, while hot, into cold water; then tempered by being put on heated iron till it becomes a bright blue; and whilst still hot, it is immersed in candle-grease, where it gains a black colour: it is then finished.

Mr. Gill says[1] that, on examining some of the London Limerick hooks, as they are called, with a microscope, he found that, although the barbs had a shape somewhat resembling the real Limerick ones, yet they had first been cut with a knife, in the usual manner of making English hooks.

The village of Redditch, in Worcestershire, the chief seat of the needle trade, produces most of the English fish-hooks. The manufacture both of fish-hooks and needles was illustrated in an agreeable manner at the Great Exhibition by men who went through all or most of the operations required in the production of those articles. The first operation in making fish-hooks is to cut the wire into lengths, which vary according to the quality of the hook: thus in Fig. 934 *c* is the finished work made out of the wire *a*. The lengths of wire are softened by heat in a furnace. A small standard, about 2 inches in height, 1 inch long, and half an inch broad, is fastened to the bench at which a workman is seated. On the upper face of the standard are three holes, into which the ends of three wires are inserted. The holes are so contrived that the wires are all at the same distance from each other, and their ends in the same line; so that if a mark is made across three wires inserted in the holes, the mark is upon each at the same distance from the ends. In this way, thousands of wires, originally of the same length, can be marked, all the marks being equidistant from the ends. By the side of this standard is a contrivance for supporting a knife which can be moved with a certain force in one particular direction. The workman, thus provided, takes up three wires of the proper length, and inserts their extremities into the three holes: he rests the point of a narrow-bladed knife in the rest, and pushing the knife from him towards the point of the wires and along their upper surface, beginning at a certain point near the end, he cuts up a portion of the metal, as in *b*. Entering from the surface and going gradually deeper, the barb or *beard* is thus pointed. Taking out the three wires, he throws them aside, and cuts another three as before. Some skill is required in inserting the three wires into their respective holes, in adjusting the knife so as to commence the cut exactly in the right place, and in making the cut of the proper depth, so as to give the required length to the barb. The next operation is to point the end of the hook, as at *c*, which is done by filing, the wire being grasped with a pair of plyers, and the end placed on a piece of box-wood. The hooks are next to be rounded, or bent into the circular form. This is done by means of a small block of wood, from the end of which projects a piece of thin brass bent as at *f*. At one end is a small notch, into which the barb is placed: the wire is then twisted over the convex surface of the brass, which gives it the bend shown in *d* and *e*. The wire is not bent round equally, but rises somewhat; that is, the man does not bend the wire round the brass slip on the same level, but in approaching the end, he raises his hand, and thus the hook is bent upwards at a particular part. A man can bend almost sixty hooks in a minute, giving to each one the particular bend required. The end of each hook is next flattened, as at *e* and *g*, to afford a hold to the silk or other fastening used for uniting the hook to the fishing-tackle: this is done by giving the end, which is placed on an anvil, a smart blow with a small hammer. The hooks are next hardened; then tempered at a sand-bath heat, properly regulated; next scoured in a rotating barrel, containing emery and soap; and lastly, blued at the required heat in a sand-bath.

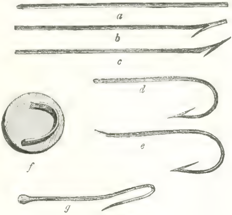

Fig. 934.

FIXED AIR, see Carbonic Acid—Coal.

FLAME, see Candle.

FLANNEL, see Wool.

FLAX (*Linum usitatissimum*), an annual plant of fragile appearance, sending up slender fibrous stalks, two or three feet high, with narrow alternate leaves, and delicate blue flowers. These are followed by globular, many-celled seed vessels, containing bright

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(1) Technical Repository, vol. iv.

slippery brown seed, flattened and elongated. The stalks of this plant are hollow pipes, surrounded by a fibrous rind, the filaments of which furnish to the manufacturer the material for cambric, linen, and other similar fabrics.

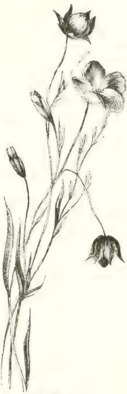

Fig 9'5. FLAX.

The frequent mention of fine linen in Scripture must be remarked by every reader of the Old Testament, and the evidence which is afforded by the unrolling of Egyptian mummies, that the fine linen of Egypt was actually woven from flax, is sufficient to prove that the same plant which we now employ, furnished one of the most ancient manufactures known. The fineness of some of this linen compared with what is woven in Egypt at the present day, also shows that the ancients had arrived at a high degree of skill in the preparation of this valuable substance.

From the time of the Romans, the produce of flax has been known in the British Isles, but our country has been very slow to avail itself of the fact that the plant can be successfully cultivated on British soil. Notwithstanding various inducements that have been held out by the government, flax has been neglected, or only very partially grown; it has also obtained a bad report, as an exhauster of the soil, while in fact, the imperfect mode of culture, and not the plant, is in fault.

Recent discoveries have, however, given a new importance to the cultivation of this crop, and flax now promises to afford a British material for British manufacture, instead of being ranked among foreign and imported goods.

"The animal and vegetable world," says Mr. Mac Adam,[1] "pretty equally divide the supply of the principal articles of clothing required by the human race. From the former we obtain wool and silk; to the latter, we are indebted for cotton and flax. Of these four substances, which enter into the composition of at least nine-tenths of the clothing of the civilized world, one (cotton), is the exclusive production of the regions bordering on the torrid zone; another (silk), although it has, to a trifling extent, been cultivated in Great Britain, may also be considered as naturally the production of the same countries, since the silk-worm does not flourish so certainly in our climate; a third, (wool) is largely obtained at home, and gives employment to a flourishing branch of British farming; yet it is understood that the wool of our islands is inferior for felting to that of foreign countries, and cannot be substituted beyond a certain proportion, or for certain kinds of cloth. The last mentioned, flax, is the only one of the four for which our soil and climate are absolutely suited, and where a native-grown article might be substituted to a very large extent, if not altogether, for the foreign import."

It is calculated that upwards of one-tenth of our whole population is dependent upon the various branches of the cotton, flax, wool, and silk manufactures, and that the capital embarked in them is not less than one hundred million pounds sterling. The whole of the raw material employed in these manufactures is in one form or other obtained by agricultural labour; yet of this labour only an extremely small amount is furnished by the inhabitants of Great Britain. Perhaps it is this fact more than any other, that has given rise to a spirit of rivalry between manufacturers and agriculturists, and to a jealous apprehension that the prosperity of the one is attained at the expense of the other. In support of this surmise, we may notice that the woollen manufacture, which really does bring into request a regular amount of home labour, is viewed with far more friendly feelings by cultivators of the land than any other branch of factory employment. Their interests are immediately concerned in its prosperity, for although British wool is seldom used without some admixture of foreign, yet the wool market is a most important source of profit to the farmer, and there is a constant demand for the produce of his flocks, with a fair encouragement to attend to the improvement of the fleece. The cotton and silk trades must in the nature of things be carried on independently of the British farmer, but we trust there will not long exist a reason why we should be altogether dependent on foreign nations for our flax, and why the small degree of cultivation long bestowed upon this crop in the sister island, should not extend till it becomes a large and important branch of farming operations throughout the country.

The Royal Agricultural Society of England deemed the subject of the growth of flax in these islands of sufficient importance to warrant their offering a prize for the best essay on the reasons, general and particular, in favour of extending the growth of flax in this country, and what are the considerations adverse to this practice, the most approved methods of cultivating the plant, the best mode of saving the crop, and preparing the flax for the market, and in what way the whole or any portion of the seed may be saved with the least injury to the fibre, and how the seed may be most profitably applied by the farmer. The successful essay was that of Mr. Mac Adam, from

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(1) "On the Cultivation of Flax," by James Mac Adam, Jun. Secretary to the Society for the Promotion and Improvement of the growth of Flax in Ireland. This Essay obtained the Prize of Twenty Sovereigns, or a piece of Plate of that value, offered by the Royal Agricultural Society of England, and is inserted in the Eighth Volume of the Society's Journal.

which we derive some important particulars affecting the question.

Flax is indigenous to several countries of the East, where it has been grown, spun, and woven into textile fabrics from a remote period of antiquity; but it is found to be specially adapted to temperate climates, so that when transported from the warm climates of which it is undoubtedly a native, the quality of the plant for the finer purposes of manufacture is considerably improved thereby. Flax is grown at the present day in all the northern countries of Europe, as well as in Sicily, Italy, and on the coasts of the Mediterranean, to a considerable extent in India, and latterly it has much increased in Egypt; North America also produces much flax, principally valued for its seed. To Britain it was brought by the Romans; but it was probably known in Ireland at a much earlier period, by means of the Phœnicians.

A slow steady growth is required to produce the best quality of fibre in this plant; when reared in hot countries, the seed is superior in quality, but the fibre is wanting in delicacy and elasticity. Egypt is in some degree an exception, for the flax grown there is favoured by the rich alluvial soil of the Nile; yet with this advantage, and with every effort to improve the cultivation, it still fetches an inferior price in the market. On the other hand, in countries approaching the northern limits of the temperate zone, the short hot summers induce too rapid a growth, and although the quantity of fibre is good, the quality is not first-rate. This is the case with Russia, which out of an export reaching to 40,000 or 50,000 tons per annum, does not sell at a higher price than 48*l.* per ton, while the flax of Holland and Belgium sells at 150*l.*, or sometimes 180*l.* per ton. The consumption of flax varies in this country from 80,000 to 105,000 tons per annum, and of this about 35,000 tons are estimated as the produce of the British Isles, chiefly of Ireland.[1] The greater part of this amount is spun and woven into various fabrics, from the coarsest canvass to the finest cambric, but a great deal is exported as yarn to Germany, France, and Spain, where it may take the form of the roughest sail-cloth, or be manufactured into the most delicate lace. Our imports of flax, in the form of fibre, seed, and oil-cake, are extremely large. In 1844, they amounted to a sum exceeding six millions sterling, and since that year the quantity has been on the increase.

The capability of Great Britain and Ireland to produce this crop in perfection is now generally admitted; but the want of care in its cultivation, which characterises our people, and especially the Irish peasantry, is also fully known. Among the documents published by the Belgian government in 1841, on the cultivation of flax in that country, is one in which the following statement occurs.—

"The flax of Ireland, when first pulled, is as good as ours, but the Irish are negligent. Our flax is immediately put in water, theirs is left to get heated in the air, while they go away to drink and enjoy themselves. Our peasants are watchful, and take out the flax at the end of five or of eight days, according to the condition they find it in, the Irish do it just when they please. Our flax, when covered with mud, is spread out carefully in a fine meadow, when the first shower cleanses it; in Ireland, it is thrown down almost anywhere. The women, with us, often take the preparation of the flax upon themselves; but in Ireland, the flax is prepared in mills. We have sent some families to England, who have since returned, and they inform us that very good flax could be reared in that country. During the war, when neither we nor Holland exported flax, the English contrived to produce equally good linen with that which they manufacture at the present time; they then cultivated good flax in Yorkshire and in Ireland, but since that time they have neglected its culture."

In confirmation of this favourable opinion of British flax, we have the fact that some fine samples, grown in Norfolk and Bedford have realized, the former 85*l.*, the latter 100*l.* per ton, while occasional samples of Irish growth have brought as high prices as the best Belgian flax. The entire quantity required for British manufactures might undoubtedly be grown at home, with great advantage to our islands, were the culture sufficiently understood to make these favourable results more frequent, and could a ready market be obtained. In that case, the crop would occupy nearly 400,000 acres annually, and if the amount required for feeding cattle were added to this, not less than half a million acres would be needed for the flax crop of Britain.

Our climate is peculiarly adapted to the growth of flax, but some districts are more favourable than others. Those which possess the most equal temperature are the best. A regular supply of genial moisture in spring, without an excess of wet in autumn is most advantageous, and the plant will flourish at a considerable altitude under such circumstances, having been grown with success in county Wicklow, Ireland, at a height of 1060 feet above the sea level.

Our spring is more favourable to flax than that of Belgium, since the long and severe droughts in that country cause the crop to fail every three or four years, from this cause alone. But our summer is not so favourable as theirs, for towards the end of July when the pulling time approaches, the heavy rain and perhaps hail which we frequently have, is very injurious to the crop, causing it to rot upon the ground, or discolouring the stalk in a way which no after care can remove. In growing flax, an open situation is to be chosen, and by no means a field sheltered with trees.

This crop accommodates itself to a great variety of soils; flourishing on sandy loams, light and heavy clays, marly, peaty, chalky, or alluvial soils. But a mixture of sand and clay is considered the best, especially where the subsoil is of clay. Very light sandy soils will not afford good crops without a large supply of manure. Flax worth 70*l.* per ton has been

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(1) Ireland produces from 25,000 to 30,000 tons per annum; the remainder is grown in Yorkshire, Somersetshire, and the south of Scotland.

grown on an Irish bog, reclaimed three years before, and having a subsoil of gravel and clay. Flax will not bear to be sown at very small intervals on the same soil. In this respect the practice of the Irish and Flemish is to be condemned. It was formerly sown, as a general rule, after potatoes; but this custom has given way to the better plan of sowing on wheat, oats, or barley stubble, which ensures a much better quality of fibre, though not quite so full a crop. Very good crops are also obtained after clover lea.

One of the greatest advantages attending the culture of flax is, the short time it occupies the ground; namely, from April to July. This allows of another crop being taken from the soil during the same season. Grass or clover is generally sown with flax in this country, so as to give a crop the following year; but in Belgium the white carrot is frequently sown broadcast with flax, and the pulling of the flax loosens the mould round the young plants, so that they increase rapidly afterwards, being generally top dressed with liquid manure. Rape, winter-vetches, or turnips of the stone or Norfolk globe varieties, may be advantageously grown with flax, and used before the following spring. Flax culture can generally be best followed after any white crop, except on very poor land: soil which has lain long in pasture has yielded valuable crops of flax, having been planted first with potatoes, then with grain, and afterwards with flax.

After thorough ploughing and pulverization of the soil, the land for a flax crop is laid out in broad flats, not in ridges, and a roller is passed over the ground to consolidate the surface. A short-toothed harrow follows, to prepare for the seed, which is carefully chosen, Riga seed being the favourite in England and Ireland. This is received in barrels, containing 3½ bushels, and covered with a coarse linen bag. The barrels are branded in Russia by government officers named *brackers*, who classify the seed as it arrives from the interior, and arrange it under the terms, "sowing seed," "rejected sowing seed," and "crushing seed." These varieties are sometimes, however, fraudulently mixed. Dutch seed, reared from Riga, but of the second year, is also much esteemed: in some respects it is superior to Riga, being generally unadulterated, and much more carefully cleaned. The respectability of the dealer is the best security for obtaining good seed. That which has a shining slippery appearance, and a brownish red colour, without being too plump, is the best. The quantity sown per acre varies from two to three bushels; the former for poor, the latter for rich soils. Thin sowing promotes a coarse growth of the plants, and deteriorates the fibre: thick sowing induces the plants to spring up with tall and slender stems, of fine fibre. The seed is sown broad-cast, and another person follows immediately after, to scatter clover or grass seed. The whole is then covered by a light seed-harrow, and rolling finishes the process. It is established as a good system, and a great saving of expense, for the English grower to save sowing seed the first year from Riga or Dutch seed. Some now sow all from their own seed, except an acre or two from foreign seed, to keep up the supply.

When the young plants have risen to the height of two or three inches, they are carefully weeded by women or children, creeping along upon their hands and knees, and keeping their faces to the wind. This does not crush the plants so much as trampling on them by the feet; and if it be done on a breezy day, the wind will soon raise the young plants to their former position. In Belgium and Holland the crop is weeded twice or thrice in this way. In this early stage the flax is in its most critical position: very dry weather will scorch its delicate fibres, and cause it to wither and die. A water-cart has in some cases been used with good effect, going regularly over an acre a-day. The delicate blue blossoms of the flax open in June, when it is one of the most beautiful of crops. These are succeeded by seed-bolls, the state of which affords the best criterion for judging of the maturity of the crop; therefore they are to be frequently examined. The Dutch method is daily to take one of the ripest capsules and cut it horizontally with a sharp knife: if the interior is whitish and watery, the crop is not ripe; if it be firm and of a dark green, the flax is fit for pulling. If left long after this, the seed will drop, and the plant will die; but it must be pulled before its juices are exhausted, and while the fibre is consequently silky and elastic.

The great objection urged against the culture of flax is, that it is an exhausting crop; and this is quite true, for it abstracts a larger amount of nitrogen from the soil than many other crops. But under the new mode of management, copied from the careful systems of the Continent, this objection is completely set aside. The restoration of the steep-water and of the woody portions of the plant, with the husks of the seed, to the soil, completely renovates the land, making it as well fitted to produce any crop as before. Formerly, the most wasteful system was employed in this respect. The flax was pulled without the separation of the seed, which was consequently lost; and the steep-water and other refuse was never economised for manure. The large amount of labour required to grow and prepare it is another objection; but where labour is plentiful this can scarcely be maintained as an objection, especially as the value of the fibre increases according to the trouble and care with which the various processes are carried on. The flax districts of Belgium are able to boast of having no poor, for the whole population is employed in the work during the winter.

The motives to a fair trial of this crop at the present period are very many. Not the least important is that which arises from a deficiency in the supply of cotton from the United States, which deficiency threatens ere long to throw a large number of our working population out of employment. Recently, also, there are signs of a similar deficiency with respect to flax, and the linen trade is confessedly retarded by the limited supply of the raw material from Russia, Belgium, and other flax-producing states. It is, therefore, not without reason that enlightened agriculturists, both of England and Ireland, have taken up the subject, and that the Royal Flax Society is labouring to disseminate sound information respecting the culture of a plant which has been viewed with prejudice on account of former imperfectly conducted attempts, which led to no favourable results. One thing is certain: flax is well adapted to our soil and climate. It has been grown upon reclaimed Irish bog, on the summit of the Wicklow mountains, and on the western shores of Galway and Mayo; in the highlands of Scotland; in the fen districts of England; upon the Beacon Hill in Norfolk, and in the midland counties: upon every variety of soil.

Under the present mode of treatment it is by no means an exhausting crop. Lord Monteagle states, that the cultivation of flax has actually improved some poor land on his estate; and that no meadow yielded such capital grass as that on which the flax had been grown. Other experienced flax-growers have obtained similar results. And not only is this crop non-exhaustive, under proper management, but it is also fairly remunerative to the grower. In a report of the Royal Irish Flax Society, particulars are given of the flax-crops of fifty-one farmers of the county of Down, the average profit being at the rate of *7l.* 1*s.* 4½*d.* per acre. This was from the fibre only, for not one of these growers saved the seed. Where the plant is cultivated with a view to the seed alone, and the stalk is merely used as litter, the results are also very favourable. The published experience of a grower who saved both seed and fibre shows that a profit of *6l.* per acre over that of the wheat crop may be obtained in this way.

The reason why the culture of flax, under these encouraging circumstances, does not become rapidly and generally prevalent, has yet to be told. There is at present a certain degree of difficulty and uncertainty in finding a market for it. Lord Monteagle has laboured to restore the cultivation of flax in his part of Ireland, which, he says, had ceased "on account of the want of markets for the produce." His tenants, with those of the Earl of Devon and other influential landholders of the district, had responded to his labours, had grown good flax, and received the favourable notice of the Flax Society. His lordship's own sample was valued at *63l.*, when prices were very low, and would have afterwards been *100l.* His tenants did not, however, succeed so well as himself: they could not transport the flax in its bulk; they had no water-power, and he was unwilling to erect steam power till assured of a market. The consequence was, that he had to take all the flax off the hands of his tenants, and so became the possessor of more stacks of flax than of wheat, and without the means of turning them to account. While things are in this state, it is impossible that flax culture should flourish. Few persons will persevere in taking all the trouble and risk which certainly belong to this crop, unless they are certain of a ready and profitable market. M. Claussen's invention [see p. 686] would, it was supposed, open new markets for home-grown flax; but this does not seem to have been the case.

The extensive use of oil-cake for the feeding of cattle points out a great advantage to the English farmer in the cultivation of flax, over and above the actual value of the crop in other respects. The production of flax-seed on the farm would obviate the necessity of purchasing costly feeding materials, while it would also supply oil, in the course of the manufacture of oil-cake. To make this cake, the seed is crushed between metal rollers, then ground under edge millstones, then heated in a metal vessel, where it is constantly kept stirred by machinery, and the oil is extracted by pressure. What remains is the oil-cake. Horses, cows, and pigs are greatly benefited by this food. The ground-seed is also made into gruel by steeping for a day in cold water, and mixing with milk and lukewarm water at feeding-time. This is much used for young calves in the north of Ireland. In all cases where linseed is given, it should be thoroughly crushed, and ground into meal. Efficient machines for this purpose are made by the agricultural implement makers. One of these for engine or horse power is shown at Fig. 936.

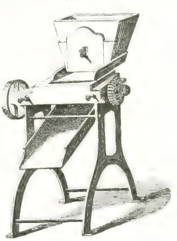

Fig. 936.

RIPPLING. After pulling, the general practice is to *ripple* the flax immediately. By this term is meant the separation of the seed from the stalk, which is done by drawing the latter briskly through a machine shown in Fig. 937, composed of a row of iron teeth, about 18 inches long, half an inch square, a quarter of an inch asunder at the bottom, and tapering slightly, so as to be half an inch asunder at the tops, which are sharpened. These teeth are screwed into a flat piece of wood or of metal, which can be bolted down to a bench or plank on which the operators sit astride, facing each other. Handfuls of flax are laid at the right hand of each rippler, and spreading it out like a fan, each draws his handful alternately through the ripple, allowing the seed-bolls to fall into a winnowing-sheet placed below to receive them. Four men, with two rippling-combs, will take the seed off more than an acre of

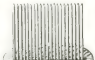

Fig. 937.

flax per day. The ripplers lay down their handfuls on the left-hand side, where they are tied up in sheaves, and carried at once to the steep-pool. The seed-bolls, meanwhile, are dried, and stored away in bags in an airy place. They should be *well dried,* or they will heat. Mr. Richard Robinson, of Belfast, has invented an improved machine for seeding flax, and also a machine for cleaning the seed.

STEEPING OR RETTING. Flax is the filamentous portion of the stalk of the plant, from which it is necessary to separate the woody part termed the *boon.* But in order to do this, the gum or resinous sap which binds the parts together must be dissolved; and the method of doing this greatly influences the value of the fibre.

The steeping of flax is carried on in some places by mere exposure on the grass to dews and rain, which is called *dew-retting, rating,* or *rotting;* in other places, by immersion in running streams. But the plan commonly adopted is that of steeping it in pools or pits filled with water; this is called *water-retting.* The quality of the water must be taken into consideration. It must be free from iron or other metallic particles, or the fibre will be discoloured: it must not be hard or spring water; but, if possible, it must be water that has flowed for some distance exposed to the action of the air. Flax is improved by a very gentle current flowing over it; and although our rivers are too rapid to allow of our steeping it in them, yet the steep-pool is most perfect when it is in communication with a river, and can have a slight current on the surface, sufficient to carry off the scum. If river-water be not available, spring-water should be let into the pit six weeks before the flax is put in, that it may have time to mellow and to deposit any calcareous sediment. In the steep-pool the sheaves of flax are packed loosely, resting on their butt-ends. It is best to put but one layer of sheaves into the pool. The flax must be covered from the light by sods, with the grassy side underneath, or by wheaten straw, kept down by stones or logs of wood. After a time, fermentation, accompanied with an unpleasant odour, ensues; but this is said to be innocuous. The water poisons fish; but cattle are not injured by it, as is proved on the banks of the Lys, where cattle drink freely of the water, while the river is full of flax for miles. The steeping of the flax must be continued until the gum-resin which binds the fibres together is completely loosened and separated; but it must be stopped before the putrefactive fermentation takes place. In order to this, a careful examination is necessary. One of the signs of the approach of this result is the sinking of the flax in the water, which may take place, according to the weather, after from six to twenty days' steeping. But a better test is the breaking of a few stalks of average fineness, and ascertaining whether the fibre can be easily pulled off, without breaking, from the internal woody part or *boon.* If so, the flax is sufficiently watered, and a longer stay would make it weak and cottony.

The removal from the steeping-pool requires care. The covering of straw is first removed to the manure-heap, being a valuable addition there, on account of its being saturated with the water of the pool. A person then stands in the water, lifting out the bundles of flax without the use of pitchfork or hook. Others receive the bundles, and set them up on their butt-ends to drain for twenty-four hours, after which they are spread out on the closest and shortest pasture, and left to be washed by showers, and softened by the action of the air. They should be evenly spread in rows, so that by means of a lath they may be turned over easily, that each side may be exposed alike, otherwise, a difference in quality and colour is the consequence. A few days or a week is occupied in grassing, after which the flax is lifted, tied up in sheaves, and packed under cover, or stacked and thatched in the rick-yard. Here it may be kept for years; the quality rather improving than deteriorating during three or four seasons after steeping.

By the old methods of *water-retting* and *dew-retting* the plant is brought to a certain stage of decay, which causes a loosening or separation of the fibres. By either processs, from 10 days to 3 or 6 weeks is required before the flax is ready for separation from the boon, and in the meantime the waters and the atmosphere of the district are rendered offensive, and the flax itself may be stained or injured by over retting. In 1847 an improved plan of retting was introduced into Ireland by Mr. Schenck of New York, and is thus described by a writer in Newton's London Journal and Repertory of Arts, &c. for August, 1851. "The principal apartment in the building [near Belfast] contains a number of large circular vats in which the flax is steeped, and these are provided with steam-pipes connected with the steam-engine boiler. The flax to be operated upon is placed in these vats, and filled up to a given height; strong cross-bars of wood, forming a kind of framework, are then laid above the flax and secured to the respective vats, the object of this framing being to keep the flax down in the vat, as otherwise it would rise as it swelled in fermenting, and protrude above the water. When a mass of flax is thus secured, water is run into the vat, and as it becomes absorbed, more is added. Steam is next admitted into and made to circulate through the steam-pipe at the bottom of the vat, so as to raise the water to about 90° Fahr., and maintain it at that temperature. In a few hours acetous fermentation is established in the vat, and the decomposition of the resinous or gummy matter in the stalk proceeds with rapidity. After about 60 hours the decomposition is completed, and that without the exudation of any odorous or noxious effluvium. The water surcharged with the mucilage is then drawn off, the framing is removed, and the flax is taken out of the vat to be dried, either in the open air or by artificial means. . . . When the weather is favourable for drying in the open air, the flax, tied up in tufts or handfuls, is suspended in rows, tier above tier, in an open framing, covered in at top by a penthouse roof." In damp weather the flax is piled loosely in a drying chamber into which a current of heated air is passed, which quickly carries off the moisture, the waste steam from the engine being economically used for heating the air.

Mr. Bower of Leeds has patented a process for improvements in *retting* flax. The patentee has found that by the ordinary method of water-retting a portion of the glutinous matter still adheres to the fibre, and renders it unfit for the scutching. By the improved process the flax is steeped in water, warm or cold, and after a few days (six, if cold water be used) taken out and passed between pressing rollers, for the purpose of expressing the glutinous matters from the interior of the plant. The steeping is then continued for a few days, when the rolling is repeated. The flax is then dried and treated in the ordinary way, when it will be found to be much clearer of the glutinous matter than if steeped in the ordinary way for a much longer time. For the finer descriptions of flax, the plant is steeped in a solution of caustic ammonia, common salt or Glauber salt. 1lb of caustic ammonia, or of any of the neutral salts, is added to every 150lbs. of rain-water, and with this solution, at any temperature from 90° to 120°, the operation will be completed in about 30 hours. A portion of one of these solutions will greatly assist the retting process first described.

Another improvement consists in operating upon the flax in a vessel exhausted of air; the flax being first steeped in water or in an alkaline solution, the air is exhausted, and the solution acts upon the flax so quickly and efficiently that two solutions and two exhaustions suffice to get rid of the glutinous matter in the course of a few hours.

Breaking and Scutching. Nothing now remains but to fit the flax for the market by separating it entirely from the wood. This is performed in Russia, Holland, and Belgium almost entirely by manual labour, employing a great number of persons. This is partially the case in Ireland; but machinery is also largely employed. The flax prepared by hand is first bruised in a machine called a *brake*, where two small rows of iron grooves, A, A, Fig. 938, meet on the flax, which is placed between them; so that each convex part of the upper row falls into the concave part of the under row, and bruises the wood without cutting or injuring the fibre. This is worked by the foot pressing upon a flat movable piece of wood, B, which is attached by a chain or string to an iron spring, C, fixed at the extremity of the machine; or a spring-pole, D, will answer the same purpose, and give more power. After bruising in this machine, the woody part of the stem will separate freely from the fibre in the operation of scutching, leaving it in reeds. Scutching is performed with a broad flat blade of wood, Fig. 939, or Fig. 940, held in the right hand, while with the left a handful of bruised flax stems is introduced into the groove B of the stand A, Fig. 942, and beaten with the scutch-blade so as to strike away the bits of woody matter. A buff-leather belt is stretched between the stand and an upright stake C, which is inserted into the flat bottom; and after the blade strikes the flax, it falls on and rebounds from the leather, which saves much fatigue to the worker. Any remaining bits of wood are cleared away with a broad blunt knife, Fig. 941, the flax being laid across the worker's leg, which is covered with a piece of leather, and scraped in that position. An active scutcher can turn out from eight to fourteen lbs. of clean flax in the day, provided it be well watered and in good condition.

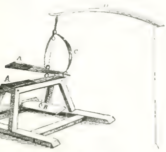

Fig. 938. The Brake.

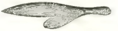

Fig. 939.

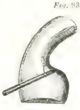

Fig. 940.

Fig. 941.

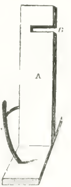

Fig. 942.

The process by machinery is as follows:—

The retted and dried flax is carried to the rolling or crushing mill, and there passed by hand between rotating horizontal rollers which crack the boon, already loosened by the retting process, and spread or partially separate the long fibres. The flax as it is delivered out of the machine, is gathered up by boys and handed to others, who submit it by handfuls to the action of rotating knives. These knives are attached to the face of a vertical wheel, several of which are mounted on one and the same shaft, at about 3 feet apart, and receive motion from the engine. There is an attendant stationed at every wheel, whose duty it is to submit the flax to the action of the knives, by holding it over a fixed bar contiguous thereto, and allowing the rotating knives to strike the flax in the direction of its length. When the boon on one half length of the flax is broken away or knocked off, the flax is turned over and the other end is subjected to a similar treatment. Further to clean the flax of the woody particles, it is again submitted to a similar operation before another set of wheels, the action of the knives being in this instance more thorough and searching, as the flax has now approached nearer to a strick of fine fibres.

The accompanying figures will show the action of Mr. MacAdam's machinery.

The bruising is effected by metal grooved rollers, four pair being necessary, fluted in different breadths. The flax is spread out on a flat table *a*, Fig. 943; the first pair of rollers taking it in, and passing it to the others in succession, when it issues completely bruised. The scutching is performed by a number of blades, *c*, of wood or iron, attached to arms, *d*, and carried round by a shaft, *e*, which is turned by the motive power. The flax is held by workers in a groove *f*, and the blades in revolving strike it quickly. The latter process is gone through three times, at different grooves, before the flax is considered finished. It is then ready for sale, and in this state it enters the flax-mill, to be acted upon by the *heckling* machine, for the removal of the tow or short staple, before undergoing the various operations of preparing and spinning to convert it into yarn. Flax is tied up in bundles of 16 or 24 lbs., the former termed the *English*, the latter the *Scotch stone*. These bundles are tied round with three or four bands, and, if well made up, can be tossed about without receiving any injury. The great markets for flax, to supply the spinning trade of the three kingdoms, are, respectively, Leeds, Belfast, and Dundee. There are commission-merchants in each, to whom flax may be sent for sale.

Two other methods of preparing flax are given by Mr. MacAdam in his valuable essay; one of which consists in drying the flax, after pulling, in stooks of a peculiar construction, then beating off the seeds, and steeping afterwards; the other, in drying as above, and then storing, the seed being beaten off during winter, and the flax not steeped till the following summer.

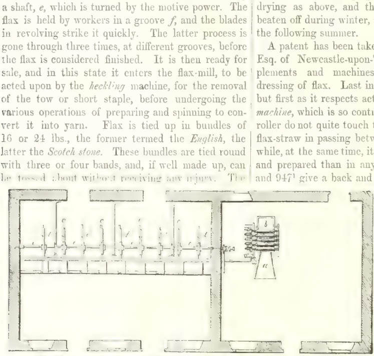

Fig. 943. PLAN OF MACADAM'S FLAX-ROLLING AND SCUTCHING MACHINERY.

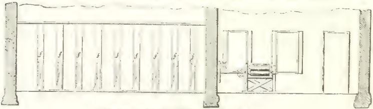

Fig. 944. FRONT ELEVATION OF THE SAME.

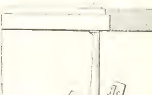

Fig. 945. END ELEVATION.

A patent has been taken out by Robert Plummer, Esq. of Newcastle-upon-Tyne, for several new implements and machines, for the more effectual dressing of flax. Last in the order of his inventions, but first as it respects actual use, is the *flax-breaking machine*, which is so contrived that the flutes on one roller do not quite touch those on another; hence the flax-straw in passing between them is less damaged, while, at the same time, it is more completely crushed and prepared than in any other machine. Figs. 946 and 947(1) give a back and side view of the flax-breaking machine, in which the rollers, five in number, are placed in two vertical series, one before the other, the front one of two rollers, the back one of three. The flax-straw, fed into the machine at *a*, passes between the top and middle rollers *b c* of the back series, and is directed downwards by the back plate *g*, so as to pass between the middle and bottom rollers *c d* of the same series, and it then passes through the two rollers *e f* of the front series. The rollers are all driven, and the ends of them have plain parts truly turned, which bear upon each other, so that the flutes of one roller work into the spaces of the next adjoining roller, and leave a space for the flax-straw to pass through; the rollers are weighted, and the pressure can be regulated as required.

In the scutching and preparation of flax for the spinning-mill, Mr. Plummer is of opinion that the machinery hitherto used for these processes has been applied on the principle of seeking to attain fineness, by reducing and destroying the character of the fibre, rather than on that of sustaining whilst cleaning it. Instead of the rigid tools to which it is usually submitted, he therefore applies brushes of whalebone, split into various degrees of fineness, bristles, or other

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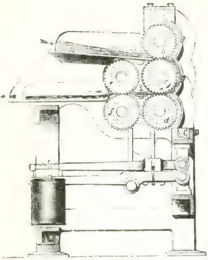
(1) In Fig. 947, the back plate for bending the straw downwards is not shown.



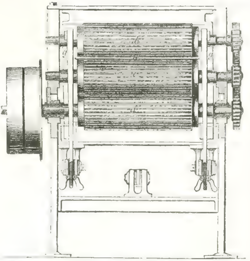


Fig. 946. (Side View.) PLUMMER'S FLAX-BREAKING MACHINE. Fig. 947. (Back View.)

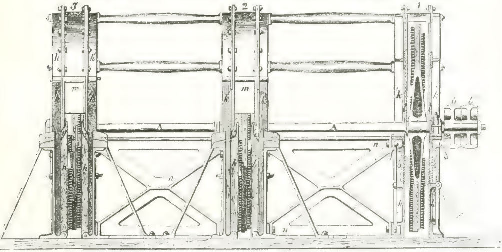


Fig. 948. FRONT ELEVATION OF [illegible] SCUTCHING MILL.

suitable materials, for nearly all the preparatory processes. The *rotary disc scutching mill* is intended to imitate more closely than has yet been done by machinery, the process of hand scutching in its pliant adaptation to the varying quality and conditions of the material to be scutched. Fig. 948 is a front elevation of this machine; and figs. 949, 950, represent one of the forms of scutching discs with the brushes fitted to it. A, fig 948, is an axle with its bearings in an independent metal framing, *k k*¹, (the upper portion being made to open,) with a lining of deals, *l l*; the metal piece *m m* at the front end, being secured by three bolts, can be easily removed for the purpose of changing the brushes in the discs. The framing is stiffened by cross pieces, *n n*, at the back end by three long bolts, and metal ferules or pipes between each stand and portion of the frame, and the whole is screwed together by nuts at each end of the bolts. A free space is left at the back end of the casing, to allow the air to be thrown off, and at the top the space is

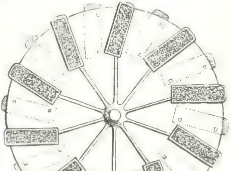


Fig. 949. SCUTCHING DISC.

Fig. 950. SECTION OF SCUTCHING DISC.

contracted, to prevent, as much as possible, the air from being carried round in the same direction with the disc. The back end of the disc casing may be connected with an exhaust pipe, to carry off the dust from each stand. The axles A, are moved by a band passing over the pulley b (b' being loose). In the ordinary scutching machines this axle carries a number of radial arms, with naked knives or blades attached to them, as in fig. 943. For these arms Mr. Plummer substitutes the disc, fig. 949, with sets of brushes fixed either to one side or to both sides of the disc, as in fig. 950, in which latter case each disc has two stands, as in fig. 948. The disc form is better than that of radial arms, as in the ordinary scutching mill, because these arms in their revolution produce cross currents of air, and cause the flax to rise from the scutching board and curl round the edges of the knives or blades, to the great damage of the staple. The brushes may be attached to the discs at any or various angles of inclination, by means of a spring catch, so that they can be readily taken out or put in, or changed from one side of the disc to the other. The outer ends of the brushes wear more rapidly than the inner, or those nearer the centre of the disc, and they are so made that the ends may be changed, and thus both ends be equally worn before the brush need be renewed. The top, t, of the scutching board, h, on which the flax to be scutched is laid, is placed a little above the centre of the axle A, so that a straight line, z, drawn from the centre of the axle, would intersect the middle of the top line of the scutching board, or nearly so, instead of passing below it, as would be the case were the scutching board placed as usual, and as is indicated by the dotted line j. The comb o^1 is of steel wire, and is used to clear the brushes of any fibres adhering to them: the points of the comb may reach only to the face of the brushes, or may penetrate a short way into the brushes: the back of the comb is fixed to a door formed of a plate of iron, turning on a hinge, and secured by a catch with a handle, so that at any time the heckle may be readily cleared without stoppage to the machine. The comb may be fixed to any convenient part of the framing, and at any required angle.

The flax, while being scutched, is held in a holder instead of in the hand, as in the ordinary mills. By this means it is more fully and evenly spread out, and more thoroughly acted on by the brushes.

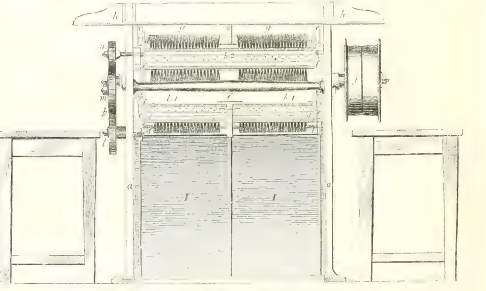


Fig. 951. SIDE ELEVATION OF PLUMMER'S FLAX BRUSHING MACHINE.

Mr Plummer has also invented a *double cylinder brushing machine*, of which fig. 951 is a side elevation, and fig. 952 an end view. In these a a is the frame-work, b^1 b^1 are two cylinders, each of which revolves inwardly upon an axis; c c are sets of brushes affixed to the peripheries of the cylinders, so that the sets of brushes of the one cylinder shall take into the vertical intervals of the sets of the other cylinder, and thus give at one and the same time a front and a back stroke to the streaks of flax let in between them: d, d, are the stripping bars, which extend along the whole length of each cylinder, and rest freely in slotted bearings e e; f f are semicircular guards, which, during a little more than half of each revolution of the cylinders b^1 b^1, confine the stripping-bars to the inner ends of their slotted bearings, and thereby regulate, as usual, the depth to which the brushes or heckles shall penetrate the streaks, but after passing a line drawn horizontally through the centres of the cylinders, allow the bars to strike out to the full extent of their slotted bearings, and thereby to doff and throw down the tow left adhering to the brushes which have just been in action: b^2 b^2 are two smaller revolving cylinders, which are fitted with rows of brushes g, g, of a similar elastic description to c, c, and so placed in respect of the larger cylinders b^1 b^1, that the brushes g, g, shall, as they revolve, come in contact with, and free the working brushes c, c from any shive or dirt which may gather upon them, or from any fibres which the stripping bars may not have sufficed to throw down; h h is the trough bolted to the framework a a, for carrying the holders which contain the streaks, and I I is an inclined grating for receiving the tow, as it is doffed or thrown down by the stripping-bars from the brushes, and precipitated downwards. Motion is given to the different parts of the machine, from any first mover, by means of pulleys or sheaves j, j, attached to the axle of one of the cylinders b^1, and by the wheel gearing in connexion therewith, marked k, k^1, l, l^1, m, m^1, and n, n^1, the relative number of revolutions so adjusted that the brushes g, g, shall revolve at twice the speed of the brushes c, c.

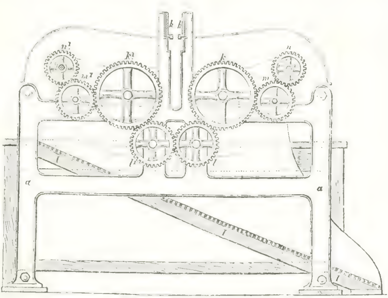


FIG. 2.—END VIEW OF BRUSHING MACHINE.

DIVIDING INTO LENGTHS. By the operation of *scutching*, the flax is freed from all its woody particles, and is ready for the flax mill, where it is converted into linen yarn. The length of the staple in flax varies from 26 to 30 or 36 inches. The part nearest the root is coarse and strong, the middle part fine and strong, and the upper part fine but not so strong. The flax is therefore divided into three lengths, and the parts from the bottom, middle, and top, being collected into separate heaps or *stricks*, several qualities of thread are afterwards formed from them. Occasionally the flax is divided into four or five lengths, instead of three, but in either case the division must be made by a tearing of the filaments instead of cutting them, as the latter would unfit them for spinning. An ingenious machine is therefore in use for effecting this in a regular manner. It consists of a number of upright wheels, and a centre wheel furnished with oval teeth. A boy, holding a handful of flax at both ends, passes it between two side wheels, which hold it securely while the centre wheel tears it across. The latter moves with great rapidity, while the holding wheels move slowly, so that the dividing wheel has time to do its work before the flax escapes from the pressure of the holding wheels.

Mr. Plummer deprecates the plan of cutting up the flax into lengths, and maintains that if a long and generous fibre be treated with gentleness instead of harshness, a considerable saving may be effected, and many advantages must accrue to the manufacturer.

HECKLING is the next operation, by which the flax is cleaned, split, and separated into fibres in parallel order, while the coarser matter is removed. The *heckle*, or *hackle*, is a sort of comb, the teeth of which are usually of iron or steel, from one to two inches in length, and very sharp at the points, which are sometimes four-sided instead of round for the better separation of the fibres. They are arranged on an equal level, being passed through holes in a brass or iron plate, which is fixed to a square or circular block of wood, rising from an oblong plank. Two or more heckles, of different degrees of fineness, may be mounted side by side on one plank; the finest may perhaps contain upwards of a thousand teeth. In heckling, the workman seizes a lock of flax by the middle, throws it upon the points of the coarse heckle, and draws it towards him; at the same time, with the other hand, spreading the flax, and preventing it from sinking too deeply among the teeth. In this way the flax is divided into two parts, the short fibre or *tow*, and the long fibre or *line*. One-half the length being heckled, the other half is turned round and prepared in a similar way. The process is then repeated on the fine heckle, until the required fibre is produced. One hundred pounds of well-cleaned flax is reckoned to yield from forty-five to sixty pounds of line, the rest being tow, boony particles, and dust. An unskilful heckler produces more tow than flax, but a good heckler throws the flax more or less deep among the teeth according to circumstances, and exercises the force and dexterity which are necessary to separate it into fine parallel lines. Sometimes between the first and second hecklings, the flax is folded up in a bundle, and beaten upon a block with a wooden mallet, after which it is well rubbed with the hands. The sort of assistance thus given to the heckler may be gained also by bruising the flax upon a board with a stiff brush, and also by boiling in potash-lye.

Heckling by machinery is generally practised in large mills. The flax being divided into lengths of about 10 or 12 inches, a certain quantity is taken, spread [illegible] iron vice or holder, Fig. 953. A number of these are then conveyed to a sort of revolving drum, and hooked on at distances of a few inches from each other; their unsupported ends falling on an internal drum covered with sharp heckling teeth, and revolving with considerable velocity, and in a contrary direction to the outer one, the motion of which is rather slow. When one machine has done its work, the holder is thrown off upon a rail, from which the *machine-minder* removes it to the second heckling machine, where the other side of the strick is heckled; thence to a third, and so on, until the proper fineness is obtained. In some machines the lower ends of the flax in each strick are first acted on, and, as the strick advances, the middle part, and lastly, the whole length of the hanging fibres are gradually brought on to the heckles, and both sides of the strick heckled at the same time. By this method the long fibres are not broken, and a smaller quantity of tow is produced. The holders are then returned to the children to be opened, the stricks of flax are taken out and replaced in an inverted position, and passed through the heckling machines as before. Fig. 954 gives a view of this machine, and the appearance of the girls at work.[1]

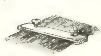


Fig. 953.

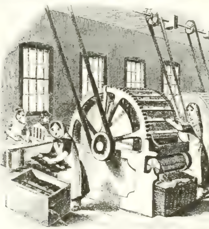


Fig. 954. HECKLING-MACHINES.

The heckled flax is greatly improved in appearance: the line consists of long, fine, soft, glistening fibres, of a bright silver-grey or yellowish colour. This alteration is due to the splitting of the fibres by the sharp points, as also to the getting rid of dirt and dust, but chiefly to the removal of the short loose fibres, or tow, of which the larger portion is obtained from the upper part of the original length. A large quantity of the dust escapes into the room; the remainder gets entangled with the tow, which must be removed, or it would soon choke up the spaces between the heckle points and prevent their further action: a series of brushes fixed upon wooden cylinders are, therefore, made to revolve while the machine is in action; the bristles, passing between the points of the heckles, remove the tow or other loose matter therefrom.

Tow, being similar to cotton in its fibre, cotton machinery, in a modified form, has been applied to spin it. The tow is therefore transferred from the brushes to a revolving drum covered with cards, as in the cotton carding-engine, from which it is taken off by a comb moved by a crank: it is carded a second time, and formed into a continuous sliver: this is transferred to the drawing-frame, and extended by means of rollers in the usual way, the fibres being laid parallel by means of a series of gills or heckling-points. The slivers, being properly doubled and drawn, are formed into rovings, and then wound upon bobbins, after which they are spun into a fine, but not very strong thread.

In heckling machines, Mr. Plummer also comes forward as an improver. We have already seen that instead of first employing the rigid tools used in heckling, he subjects the flax to his *brushing machine*, where brushes made of elastic materials act gently on the fibre, and produce a cleaner and brighter state of the flax, with less waste. In the *heckling machines*, to which the flax is then removed, brushes are again substituted to a great extent. Mr. Plummer's inventions in heckling machines comprise a *double-cylinder machine*, best adapted for cut flax, and an *oscillatory double sheet machine* for long flax, in both of which brushes unite with heckles to produce the desired effect. The advantage of *double* machines is, that they dress both sides of the flax, and thus double the quantity of work is obtained. In the first place, both sides of the flax are brushed before meeting the heckling points or pins, by which means crossed or entangled fibres are got rid of. Improved holders are also introduced, which spread out the flax better and expose it more regularly to the brushes and points. The brushes and pins are made to work close up to the holder, and the opposing set of pins is made to intersect and strike the flax so as not to injure the fibre. By this means more line and less tow is produced, and both are freed from shive and

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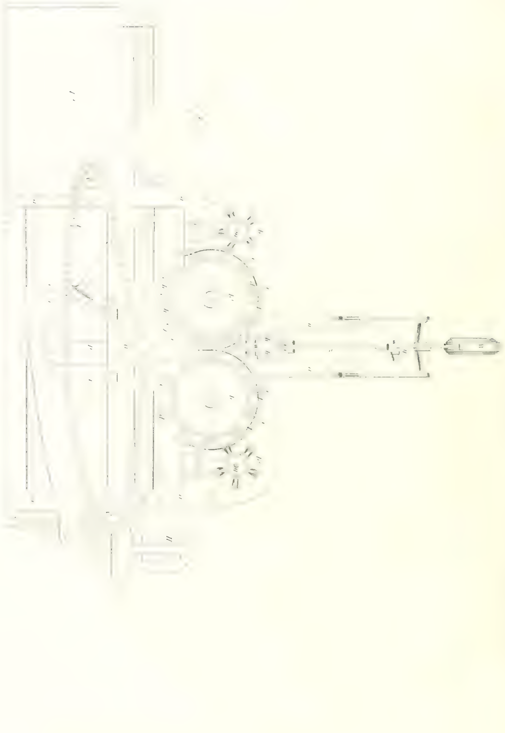
[1] The sketch for this engraving was taken in Messrs. Marshall's mill, at Leeds. The Editor remarks, in his work on the Useful Arts, already quoted: "The operations of dividing and heckling the flax, which are performed in the same room, occasion rather a dense cloud of dust and loose particles. The girls protect their hair from this dust by wearing a handkerchief tied across the head, and hanging loosely down the back; this also protects the neck and shoulders, and has a not unpleasing effect. From habit, this head dress is constantly worn in or out of the factory, serving the purpose of a bonnet, except on Sundays. The writer noticed this habit in Yorkshire only, and not in the cotton-mills of Lancashire where it would seem to be equally necessary and useful.



dirt. The tow is also delivered without the usual doffing apparatus

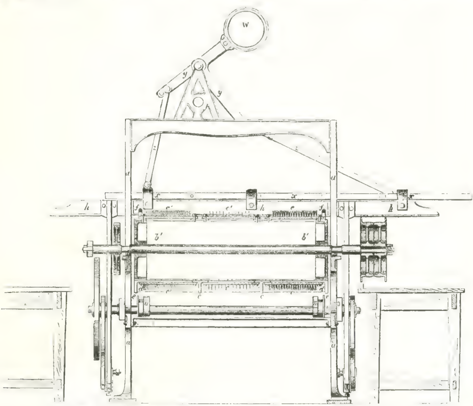


Fig. 955. LONGITUDINAL SECTION OF PLUMMER'S DOUBLE CYLINDER HECKLING MACHINE.

The steel engraving, and Fig. 955, represent a side and end elevation of the double cylinder heckling machine, adapted to the dressing of cut or short flax. There are two revolving cylinders, $b^1 b^1$, mounted in a frame-work *a*, *a*; attached to their peripheries are sets of rigid heckles, *c'*, interspersed with the sets of elastic brushes *c c*, (in any way that may be deemed most advisable.) The cylinders are also made to revolve inwardly, or in opposite directions, and the rows of brushes and heckles on the one cylinder are placed in an alternating order in regard to those of the other cylinder. There are also loose stripping bars with guards, that, besides regulating the depth to which the heckles or brushes shall penetrate, doff or throw down the tow from the brushes and heckles, and two smaller cylinders b^2, b^2, fitted with brushes, for cleaning the working brushes and heckles *c*, *c'*. One of the cylinders b^1, may, if required, be made to oscillate by means of the link h^1, h^1, which, as it rises and falls with the lifter to which it is attached, moves the cylinder in a horizontal direction to and from the other cylinder; the bearings of the oscillating cylinder being made to slide, and attached by a rod to the radius arm to which the stud-pin of the wheel m^1 is fixed, the whole of the wheels k^3, l^1, m^1, and n^1 are thus kept in gear, to answer the varying positions of the oscillating cylinder. Rotation is given to the rotating parts of this machine, as in the one first described, but the holder is made to traverse or move forward in the trough (which movement may also be applied to the brushing machine), by the combination of a rack or of a bell-crank movement with the rising and falling motion of the trough, as afterwards described. The mechanism for lifting the trough *h* is partly shown in Fig. 955: it consists of a combination of pinions, wheels, a cam, straps, pulleys, and levers such as is ordinarily used in heckling machines. When the trough is raised, it pushes up a rod *x*, Fig. 955, which is connected to the long arm of the bell-crank *y*, mounted on a standard affixed to the top of the frame-work *a*, when a weight w, which is attached to the opposite end of the arm, falls over, and causes the short arm of the bell-crank to pull in a rod *z i*, which draws forward a finger bar *x*, (of the ordinary construction,) to an extent sufficient to advance the holder the breadth of one set of heckles or brushes. The tow and shive or dirt doffed or thrown down from the heckles or brushes is in this case received upon an endless chain of bars *t*, *t*, which extend the whole length of the machines under the heckles and brushes, and are connected together by two side bands. The chain of bars revolves round two friction pulleys v v, and takes into two pinions *u*, (one on each side); by means of pinions, rotation is given to the chain from the same first mover by which the other parts of the machine are put in motion. The shive or dirt falls through between the bars on to the floor, while the tow is carried forward on the top of the bars and delivered into the trough T'. To separate the tow doffed from each set of heckles or brushes, the space between the endless chain of bars and the cylinders is divided by partitions into as many compartments as there are sets of heckles or brushes, and the receiving trough T', is also divided into a corresponding number of compartments.

A view of the holder for this machine is given in Fig. 956, a cross section, and Fig. 957, a longitudinal section. It consists of two plates, Nos. 1 and 2, connected transversely by a screw-bolt S, and having flanges A, A, at their upper edges, by means of which they are supported in the trough *h*. The plate No. 2 has two flanges B, B, one on each end, which come within the two flanges A, A, of the plate No. 1, and thereby confine the streak at the edges. The inner face of the plate No. 2 is planed perfectly true, and covered with felt, cloth, or some other soft or yielding material; but the plate No. 1 is made, on its inner face, with flat beads C, and flat grooves D, in alternate order, so that the streak of flax or other material may be more firmly compressed between the plates without being unduly crimped. At their under edges E, the plates are chamfered off to admit of the holder coming lower down. By this mode of construction, the pins or studs ordinarily made use of, to confine the outer edges of the streaks, are dispensed with, and a greater breadth is obtained whereon to spread the streaks, and the holder is also narrowed and rendered more easy to work.

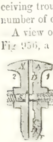


Fig. 956.

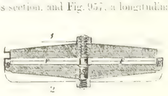


Fig. 957.

SORTING.—The heckled flax or *line* is sorted preparatory to drawing and roving. Sorting is an operation in which the sense of feeling is cultivated to a remarkable extent, the *line-sorter* judging of the various degrees of fineness by the touch rather than by the eye, and by this means separating the stricks of heckled flax into several divisions according to their fineness. The line-sorter seats himself before a *sorting-box*, which is a kind of table containing several boxes or divisions for receiving the various qualities of line, which are called 2lbs., 3lbs., 3½lbs., 4lbs., 5lbs., 5½lbs., 6½lbs., &c., from an old method of comparing fineness and weight, which will be further noticed under *Reeling*. In the course of sorting, the line is frequently drawn through a block heckle, in order to keep the fibres parallel. The tow is also sorted into qualities preparatory to spinning.

SPREADING, DRAWING, AND ROVING.—The sorted line is next converted into ribands or slivers. For this purpose it is spread upon a feeding cloth in such a manner that the ends of the second strick reach the middle of the first. In this way a uniform thickness is preserved, since the heckled stricks are thicker in the middle than at the ends. The flax is then passed between one pair of rollers, which deliver it through gills or heckling points to a second pair, which, moving with much greater speed than the first, increase the length and diminish the thickness of the flax. During this operation the flax receives no twist, but is converted into a flat narrow tape or riband, which is received into a tin can. When the can is full it is taken to a drawing or *spreading* frame, where a number of slivers are united and drawn into one length. Three sets of these frames are often used, and when the writer inspected the processes at Messrs. Marshall's mill, 8 slivers were drawn into 1 at the first frame; 12 into 1 at the second, and 15 into 1 at the third. The frames are attended by young women, each of whom has the charge of four.

The slivers next go to the roving frame, where they receive a slight degree of twist and are wound upon bobbins preparatory to spinning.

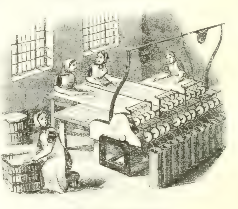


Fig. 958. SPREADING FRAME.

SPINNING.—The extension of the factory system has had the effect of banishing the flax and cotton spinning wheel, as well as the hand loom, from the cottage of the weaver. During many centuries the production of linen in Ireland was so common that it was almost regarded as the national manufacture. Before the establishment of factories "the spinning of yarn by hand was the ordinary occupation of the females of almost every family in the province of Ulster connected with the linen weaving. It was a constant source not only of employment, but of fair, and sometimes even liberal profit, and of a nature eminently adapted to the social and physical capabilities of those who followed it."[1] The substitution of mill-spun yarn for the hand-spun has superseded the domestic spinner and weaver.

The spinning of flax differs little from the throstle-spinning of cotton, [see COTTON, page 465,] but the fibres of flax have not the same tendency to entangle themselves together as those of cotton, therefore it is

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(1) Report of R. M. Muggeridge, Esq., on the Linen Manufactures of Ireland.

necessary to moisten them with water to make them adhere to each other, and also to make them more pliable and easy to twist.(1) Until recently, the flax for machine-spinning was moistened with cold water, but a great improvement has been effected by substituting water at the temperature of 120°, which allows a much finer and more uniform thread to be spun, and double the length to be obtained from a given weight of flax. The warm water is contained in a trough, which extends the whole length of the spinning frame, and the rapid motion of the spindle causes a dewy spray to be continually thrown off. A great inconvenience was for a time experienced by the attendants, whose clothes were completely wetted in an hour or two by this minute spray, but the use of water-proof aprons has been found a sufficient remedy. This operation, however, produces a hot steaming atmosphere, which is painful to casual visitors of a flax mill, though not unpleasant to the operatives.

The yarn, by doubling, is made into linen thread, which is bleached and formed into balls or reels. The yarn itself is wound upon reels, and then made up into leas, hanks, bundles, &c., as in the following invoice.

TWO AND A HALF YARD REEL.

120 Threads of 2½ yards..........	300 yards or 1 lea.
10 Leas..................................	3,000 yards or 1 hank.
20 Hanks................................	60,000 yards or 1 bundle.

(Three bundles are usually put together in one bunch.)

ONE AND A HALF YARD REEL.

100 Threads of 1½ yard	150 yards or half a lea.
10 Half leas..........................	1,500 yards or 1 hank.
40 Hanks...............................	60,000 yards or 1 bundle.

(Six bundles are usually put together in one bunch.)

The fineness of linen yarn is reckoned by the number of leas to the pound weight. In 1839 the common limit of fineness of linen yarn spun by machinery was about 150 leas, and this was all used for different descriptions of common linens, not being sufficiently fine for the manufacture of fine cambric or of lace; but yarns from this limit up to 240 leas were spun by machinery, for the manufacture of Irish lawns and coarse cambrics. At the same time yarns of from 300 to 400 leas were spun by hand.

In sorting line, the various qualities are divided into 2, 3, 3½ pounds, &c., as above mentioned. In linen yarns, the bundle of 60,000 yards is sometimes called by its number of leas per lb., or by the weight of the bundle. Thus a bundle of 25 leas to the lb. weighs 8 lbs.; a bundle of 50 leas to the lb. weighs 4 lbs.; a bundle of 100 leas to the lb. weighs 2 lbs.; so that 8 lbs. and 25 leas, and 4 lbs. and 50 leas, and 2 lbs. and 100 leas, are synonymous terms, as far as the size is concerned. In sorting, a certain quality of line will spin to a certain size or weight per bundle, and it was formerly the custom of line-sorters to call certain qualities 2 lbs., 3 lbs., 3½ lbs., 4 lbs., &c., because that quality of line would spin to that weight per bundle. The same standard and name are still retained by line-sorters for the same quality of line, but from improvements in machinery, and other causes, 5¾-line can now be spun to the size of 3 lbs. the bundle, and even finer.

STATISTICS. So long as the production of linen yarn was confined to the spinning-wheel, linen was a costly article, and the trade necessarily limited. The powerful effects upon the wealth and industry of the country, by the introduction of cotton machinery, was soon extended to flax. Mr. Marshall states that "before flax was spun by machinery, the French and Belgian spinners were so superior to anything that we had in this country, or in Ireland, that the linens were a great part of them imported from Flanders, or from the north of Europe."

Mills for spinning flax were first constructed at Darlington, about sixty years ago, and the improvements which have been made in spinning and in bleaching, &c., have raised the British trade to the same level, and even above that of foreigners; so that besides supplying our own markets, we export largely. Our exports of linen yarn are considerable. In 1848 they were of the declared value of 493,449*l.*; in 1849, 737,650*l.*; in 1850, 887,295*l.*; in 1860, 1,801,272*l.*; in 1861, 1,605,800*l.* To some countries, France for example, our exports have gone on gradually declining in consequence of the success of native manufactures. Our chief exports of linen yarn are to the Hanse Towns, Holland, Belgium, Spain, and the Canaries.

In 1861 there were imported into the United Kingdom, of flax and tow, or codilla of flax, 1,333,679 cwts., of which 1,031,044 cwts. came from Russia and Prussia.

The principal flax mills in England are in the West Riding of Yorkshire, and its immediate vicinity, and in Lancashire, Dorset, Durham, and Salop. In Scotland, Dundee is the chief seat of this trade; and in Ireland, Belfast. Some years ago Mr. Marshall stated that the linen trade had doubled in England, and trebled in Scotland, within half a century; and that the improvements in machinery had been such, that in order to keep pace with them he had re-constructed his mill twice within that period. This must have been a costly proceeding, since the number of persons employed by him amounts to above 2,000.

Fig. 959. THE ROOF OF MARSHALL'S ONE-STORY FLAX MILL.

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(1) For coarse purposes, flax can be spun dry, and is so to a great extent in the Scotch factories.

Fig. 959 is the appearance of the roof of Marshall's one-storied flax mill, a description of which is given in the article FACTORY.

FLAX, COTTONISING OF. An interesting discovery has been made by a gentleman, formerly an extensive cotton-grower and slave-owner in the Brazils, by name the Chevalier Claussen. This is no other than that flax may be employed to a great extent in the same way as cotton, and may be adapted for mixing with wool. The important results that are likely to flow from this discovery, with the prospect of a new market for home-grown flax, make it desirable to give the details of the origin of the idea. The chevalier, it appears, was wandering along the luxuriant banks of one of the Brazilian rivers, when his attention was arrested by a white downy substance adhering to the branches of trees overhanging and touching the stream. Thinking that he had discovered some hitherto unknown vegetable substance, he collected a quantity of it, and endeavoured to ascertain whence it came. At last he traced it, not to some new plant or shrub, as he had expected, but to his own bed of flax-straw, which, long before, had been thrown as refuse on the banks of the river. To this heap the swollen waters had occasional access; fermentation, and decomposition of a portion of the plant had taken place, and, in time, the influence of natural chemistry had so separated the filaments of the flax fibre as to give the mass a cotton-like appearance; and some of it, having been washed into the river, had been arrested by the over hanging branches. Although the substance thus accidentally discovered was far from being in the state which would fit it for the hands of the cotton-spinner, yet, even in its then imperfect condition, it led the chevalier to entertain the idea of completing, by the aid of chemistry, that which nature had partly accomplished.

M. Claussen accordingly set on foot a series of experiments, which have led to remarkable results. He has cleared away difficulties that have long been felt in every stage of the preparation of flax, and has proved that the *cottonising* process may be carried on successfully in this country. It has been known for some years that the fibre of the flax is separable from the straw without steeping, and any one rubbing a ripe stalk of flax between his fingers, may find that a partial separation takes place in his hand. But it was for Claussen to turn this knowledge to practical account by constructing a machine which should enable the grower to effect this desirable separation, and thus reduce the bulk of a crop which previously had either to be taken to market as it was grown, or to be subjected to troublesome and expensive processes. This machine does little more than separate the straw, the fibres being still partially held together by the gum-resin. But even now, the flax is in a state which makes it suitable for strong and coarse fabrics, such as sail-cloth, ropes, cordage, canvas, &c., and it may be profitably applied to many of these uses as a substitute for Russian hemp. In order to fit it for the linen manufacturer, and also for the cottonising process, a more complete separation of the fibres must be attained by steeping. But this, according to the existing plan, occupied too much time, and also was not sufficiently uniform in its action to satisfy Claussen. He therefore adopted the plan of boiling the flax for about six hours in a weak solution of caustic soda, or if time could be allowed the solution was heated to about 150°, and the steeping continued for twelve hours. Caustic potash or lime may be used instead of soda. This completely dissolved the resinous and oily substances of the plant, producing a soapy kind of liquid, which removed at the same time all extraneous matter, leaving it, unlike flax steeped by the ordinary method, perfectly free from stain and impurity. By this valuable method, the preparation of long fibre is not only effected in one day, instead of perhaps a dozen, but it is also uniform in strength, and can be bleached and dyed with much less trouble.

If the fibre is required to be *long*, such as is now commonly spun in flax machinery, the free alkali adhering to the fibre is got rid of, together with any remaining gummy matter, by steeping it for about 2 hours in water acidulated with sulphuric acid, or instead of this, the wet flax is exposed to the fumes of burning sulphur. The acid combines with the alkali, forming a sulphite or a sulphate, according to the acid employed. The flax is next washed in water, and then bleached.

In the bleaching process, a great portion of the chlorine or chloro-compound is kept in a combined state, and reserved for future use. The goods, after having been passed through the bleaching liquor, (such as a solution of hypochlorite of lime,) are steeped in a strong solution of some salt whose acid has a more powerful affinity for lime than the hypochlorous acid. Thus a strong solution of sulphate of magnesia may be employed, the sulphuric acid of which, having a strong affinity for lime, combines with the earthy base of the bleaching salt, and forms sulphate of lime, and the chloro-compound being thus liberated, unites with the magnesia of the sulphate of magnesia and forms a new salt, hypochlorite of magnesia, having bleaching properties similar to the lime salt first employed This newly-formed compound may be, in the next instance, used as a primary bleaching agent, and may again be subjected to the process of double decomposition as in the foregoing example. The advantage of this method is, that the chlorine, instead of escaping, or remaining long enough in contact with the goods to injure them, is made to form a new salt, having bleaching properties. By another method of bleaching, the goods are exposed to the fumes of burning sulphur while still wet with the solution of bleaching liquor, such as hypochlorite of lime. A portion of the sulphurous acid (itself a bleaching agent) combines with the base of the chloro compound salt to form a sulphate of lime; and in this way the chlorine remaining in the wetted goods is liberated, and allowed to act freely upon the articles to be bleached.

The flax, being washed and dried, is ready for breaking and scutching, as in the ordinary manufacture of long flax. It is, however, advantageous to pass the straw between rollers, so as partially to break it, before submitting it to the action of the chemical agents above noticed.

If the fibre is required to be short, so that it may be felted or carded, and adapted for spinning on cotton, silk, wool, worsted, or tow spinning machinery, several additional processes are required. First, by a nicely adjusted machine, similar in operation to an ordinary chaff-cutter, the flax is cut into short lengths, corresponding with the staple of cotton. Next by an ingenious application of chemical forces, the harsh and elastic fibres of the flax are brought to the soft and downy texture of cotton, thus overcoming a difficulty which seemed for ever to preclude the possibility of spinning flax upon cotton machinery. The fibres of the flax, under the microscope, present the appearance of small bundles of minute hair-like substances, and it was this fact which led Claussen to seek some further mode of subdivision beyond any that mechanical means could furnish. It has been already stated that, instead of steeping in the ordinary way, he boils his flax in a solution of caustic soda. The flax to be cottonised, when taken out of the soda vat, is placed in another containing a solution of bicarbonate or sesquicarbonate of soda, in which it remains three or four hours till fully saturated with the salt. It is then placed in a third vat, containing a weak solution of sulphuric or other acid. The hollow cylinders of the fibres then become charged with the acid solution, which, coming in contact with the salt which the fibres had taken up before, generates carbonic acid gas, the expansive force of which splits the fibres into a vast number of ribbon-like filaments, which under the microscope present the appearance of raw cotton. Thus, in a moment, and as if by enchantment, all those minute hair-like fibres are released, and the whole becomes a soft and cottony mass. This flax-cotton, when dried, carded, and spun, will be found to produce a considerably greater quantity of yarn than that obtained from a similar weight of cotton: and so well adapted is this new substance to cotton machinery, that several large manufacturers have expressed their willingness to take any quantity that may be supplied to them. These yarns mix well with cotton, wool and silk, and dye extremely well. By the mixture of flax cotton with wool it is expected that cloths quite as durable as those made of wool alone, will now be produced at a lower price. Claussen's own estimate of the price at which flax-cotton can be produced is as follows:—"On the average, five tons of flax-straw will produce one ton of British cotton, the cost of which, at 3*l.* per ton, would be 15*l.* The expenses of breaking, cutting, and blowing will not exceed 1*l.* 19*s.*; chemical preparations and ingredients employed, 1*l.* 5*s.* Thus the total cost of one ton of flax fibre, or British cotton, equal to fair quality American cotton, would be 18*l.* 4*s.* Add to this, where required, the bleaching, 1*l.*, and the washing, drying, &c. 1*l.* 16*s.*; then the total cost of the British cotton, bleached and washed, would be 21*l.* per ton, or 2¼*d.* per pound, and which will readily sell at from 4*d.* to 6*d.* per pound." The average price of foreign cotton for ten years, from 1835 to 1845, at Liverpool, was, Upland American cotton, 6½*d.* per pound; Surat and Madras cotton, about 5*d.*

[This calculation was published in 1851. In revising it, in 1862, we have to record the want of success of the flax-cotton; and the reason for the failure seems to have been the abundance of the supply of true cotton. Now, however, that this supply is temporarily suspended, it is possible that the schemes for cottonizing flax may be revived. If so, see APPENDIX.]

An experienced flax-grower in Gloucestershire, Mr R. Browne, in common with some other agriculturists, believes that the flax fibre is materially injured by the employment of chemical processes, and that it invariably becomes weak and rotten. He describes the yarns and fabrics manufactured on Claussen's plan as deficient in strength, and inferior in quality. In answer to this statement, Claussen explains the proportions of soda and acid employed, and declares it to be impossible for them to injure the most delicate fabric. Of soda, one part in 200 parts of water, and of acid, one part to 500 of water, are all that are necessary to produce the effect,—and the soda present in the straw neutralizes the whole of the acid, and forms a neutral salt—sulphate of soda.

The question of strength and quality of fibre in flax-cotton will, however, be thoroughly tested by the experiments carried on in Manchester with the existing cotton machinery. The cloth woven on Claussen's circular loom, from yarns composed of half flax and half cotton, is even and regular in texture, and various experiments are going on with higher proportions of flax and less of foreign cotton.

An instructive series of specimens was exhibited by the Chevalier Claussen, at the Great Exhibition, intended to show the universal applicability of flax fibre to the purposes of the textile manufactures. First, there were samples to illustrate the various processes resorted to in the preparation of flax for being spun alone, or mixed with various proportions of cotton, upon any of the ordinary cotton-spinning machines. There was first the flax in the straw, as pulled from the ground, cut into appropriate lengths by suitable machinery; next came flax which had undergone the saturating process in a solution of soda, required to remove the glutinous substance which binds the fibres. Then came the fibres alone, separated from the woody substance; then the flax transformed into a cotton-like substance, by the action of carbonic acid gas in the way already described. The remaining samples were the same bleached, dried, carded, and ready for spinning: also, samples of mule and throstle yarn of various numbers, some of flax only, others of various proportions of flax and cotton. These yarns were bleached and dyed of various colours, to show that flax prepared by this process is capable of receiving the same opaque dye as cotton. Samples of grey and bleached, dyed and printed cloth woven from this flax-cotton completed the series.

The second series comprised flax-wool yarns, or those in which flax and wool were mixed in varying proportions, the flax being prepared in nearly the same way as for mixture with cotton. Flannel and woollen cloths, milled and dyed of various colours, woven from this flax-wool, completed this series. The third series consisted of yarns of flax-silk, together with samples of flax, as prepared for combination with short silk on the ordinary silk machinery. A quantity of silk woven from flax-silk yarns, completed this very interesting series. The exhibitor's method of preparing flax for spinning upon ordinary flax machinery, and for its manufacture into linen fabrics, here also received illustration.

FLINT, a mineral containing about 98 per cent. of silica, and minute portions of lime, alumina, oxide of iron, and water.[1] Its specific gravity is 2.594; hardness 7.0 to 7.25: it is rather harder than quartz, which it scratches. It is usually of a grey colour, of various shades, but sometimes it is brown, black, yellow, or red. Thin fragments of the black varieties are translucent. It is fragile, and being rarely laminated, it may be broken with equal facility in almost every direction. When first taken from its native bed, it may be split with remarkable precision with the imperfectly flat conchoidal fracture observed in gun-flints: the keen edges thus produced are remarkably perfect; far more so than could be produced on the same substance in any other manner. When the water is completely dried out of the flint, it breaks with the ordinary conchoidal fracture.

Flints are found in the upper bed of the chalk formation, where they occur in regular beds, consisting either of nodules or flat tabular masses, as in the cliffs near Dover, the hills about Salisbury, and many other places. In the south of the Isle of Wight the upheaving of the chalk strata has cracked all the flints contained in them, so that, on taking out what appears to be a perfect nodule, it falls into thousands of fragments. Flint is often found in the form of sponges, alcyonia, echinites, and other fossil remains, which appear to have formed nuclei for the flint when in a state of solution. In some cases the centre of the nodule is hollow, and its sides are studded over with crystals of quartz, carbonate of iron, pyrites, calcedony, or filled with pulverulent silica, or silex mixed with sulphur. Flint also occurs in alluvial deposits in the neighbourhood of chalk. Gravel, or *ferruginous flint*, consists principally of flints rounded by attrition, the yellowish red colour being due to the peroxidisement of the iron contained in them by exposure to air and moisture.

Flint is infusible, but it whitens and becomes opaque by the action of heat. In this state it can be more easily reduced to powder, and, as such, is used largely in the manufacture of porcelain. Flint powder, glued upon wooden face wheels, is used as a polishing material. The solid flint is used as the *bouldering stone* for rubbing down to a smooth face the laps, buffs, and glaze-wheels of the cutler. [See CUTLERY.] The siliceous portion of *flint glass*, as the name implies, was formerly obtained from flints; but a purer form of silica is now found in the sand of Alum Bay and elsewhere. Flints form a good building material, their rough irregular surfaces giving firm hold to the mortar; and they resist the action of the weather perfectly. Good specimens of flint masonry may be seen in the upper chalk districts of England.

Flints were formerly in great request for the manufacture of gun-flints, and for "striking a light" with a steel. Percussion caps and lucifer matches have nearly superseded them; but, as there is still a small demand for gun-flints, it is our duty to describe the manufacture.

The nodules adapted to this manufacture should approach a globular form, the knobbed or branch flints being generally full of imperfections. Good nodules seldom weigh more than 20 lbs.: when less than 2 lbs. they are seldom worth working. They should have a greasy lustre, and should be smooth, and fine-grained. The colour should be uniform throughout the lump, and may vary from honey yellow to blackish brown. The translucency of the flint should be such that a slice of it $\frac{1}{50}$th inch thick, placed upon print, should allow the letters to be read through it. The fracture should be perfectly smooth, uniform, and slightly conchoidal.

The tools required in the manufacture are, an iron hammer, Fig. 960, with a square head not exceeding 2 lbs. in weight, with a handle about 7 or 8 inches in length. Also a hammer of well hardened steel, Fig. 961, with two points, and a handle 7 inches long: the weight of this hammer should be from 10 to 16 ounces. A roulette or disc hammer, Fig. 962, is also

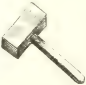

Fig. 960.

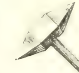

Fig. 961.

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[1] According to Klaproth, flint consists of

Silica	98.00
Lime	0.50
Alumina	0.25
Oxide of iron	0.25
Water	1.00
	100.00

Berzelius has found potash in the flint of the chalk of Limhamn, in Sweden. In 1000 parts flint he detected 1.17 potash, 1.1[illegible] lime, with traces of oxide of iron and alumina, and a small quantity of carbonaceous matter, which left no residue on being ignited, and which probably produced that colour in the flint which resembles the tint of brown rock crystal. This analysis was undertaken in order to ascertain the cause of the decomposition of the surface of a flint knot,—a change not unfrequently observed in flint exposed to the action of the atmosphere. The interior and undecomposed portion contained in 1000 parts, 1.74 potash, 5.71 lime, and 1.2 oxide of iron and alumina. The decomposed portion, which could easily be rubbed off in the state of powder, contained in 1000 parts, 0.2 potash, 3.2 lime: so that decomposition originated in the long-continued action of a liquid containing potash, which gradually replaced the lime by potash. The decomposition proceeded progressively, and had evidently commenced in the still coherent portion of the flint, and had formed a white stripe round the mass, the breadth of which varied from 0.3 to 0.4 of a line.

used: this is a small solid wheel or flat segment of a cylinder at right angles to its axis: it is $2\frac{1}{2}$ inches in diameter, and weighs 12 ounces: it is made of steel not hardened, and is fixed upon a handle 6 inches long by means of a square hole in the centre of the disc. A chisel, Fig. 963, 7 or 8 inches long, and 2 inches broad, tapering and bevelled at both extremities, is the last tool required, except a file used for restoring the edge of the chisel, which is made of steel not hardened, and is set on a block of wood which serves as a bench for the workman.

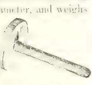
Fig. 962.

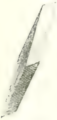
Fig. 963.

Having selected a large nodule, the workman, seated on the ground, places it on his left thigh, and breaks it up into smaller pieces of about $1\frac{1}{2}$ lb weight, with broad surfaces and an almost even fracture: this he does with the square hammer, tapping rather than striking the nodule. Having in this way got a well-shaped flint, he next chips off with the pointed hammer the white coating of the flint, which flies off in small scales. He then proceeds to chip off scales of the length, thickness, and shape required for the formation of gun-flints. In doing this, great dexterity is required. The man balances the lump in his left hand, and strikes with the pointed hammer upon the edges of the great planes. The portions thus chipped off from the pure mass of the flint—as at A A, Fig. 964, which is a cross section of Fig. 965, the shaded portions showing the points removed at each blow—are nearly $1\frac{1}{2}$ inch wide, $2\frac{1}{2}$ inches long, and about $\frac{1}{6}$th inch thick in the middle: they are slightly convex below, and consequently leave in the part of the flint from which they are separated a space slightly concave, bordered by two projecting ridges. These ridges, produced by the separation of the two scales, form nearly the middle of the subsequent piece, and such scales with a ridge in the middle are also fit for gun-flints. In this way the workman continues to chip or split the mass of flint in various directions, until the defects usually found in the interior render it impossible to make the fracture required, or until the piece is reduced too much to be easily broken.

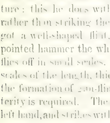

Fig. 964.

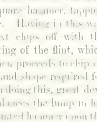
Fig. 965.

To shape the gun-flint out of these scales, the man selects such only as have the required form. He must be able to produce from every one of these scales the five different parts which constitute a gun-flint, as shown in Fig. 966; viz. A, the sloping facet or bevel which is impelled against the hammer of the lock: it should be from $\frac{2}{12}$ths to $\frac{3}{12}$ths inch thick: if thicker, it would be liable to break; if more obtuse, the scintillations would be less vivid; B, B, the sides or lateral edges, which are somewhat irregular; C, the back; D, the under surface, which should be rather convex; and F, the upper facet, which has a small square plane surface between the tapering edge and the back, for entering into the upper claw of the cock. In selecting the scales, those are taken which contain at least one of the ridges F or A. The man fixes on any tapering border of the scale to form the striking edge: he then, by means of his chisel, divides the scale into pieces of the proper width of the flint. The chisel is driven into a solid block of wood, with one of its edges upwards, that part of the flint is placed across the edge where the separation is intended to take place, and a blow from the roulette on the upper surface divides it as cleanly as if it had been cut. The back of the flint is made square by the same means. The last operation is to trim the flint, or give it a smooth and equal edge: this is done by turning the stone, and placing the edge of its tapering part on the chisel, and giving it a few blows with the round hammer.

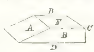

Fig. 966.

With flint of good quality a skilful workman can make 1,000 chips or scales in a day, or 500 gun-flints. In three days he can cleave and finish 1,000 gun-flints. Not more than about one-half the scales are good, and nearly half the mass in the best flints does not admit of being chipped out. One of the largest nodules seldom furnishes more than 50 gun-flints.

Such is the French method of making gun-flints. It was long kept secret; and it was not until after it had been introduced into this country that a description thereof was published by M. Dolomieu. During the war, when the demand for this article was very great, and percussion caps had not been invented, gun-flints were manufactured at Lewisham, Maidstone, Purfleet, Greenhithe, and Northfleet. Brandon in Suffolk was, however, the chief seat of the manufacture. The flints obtained in the pits below the heath were said to be of a very superior quality, lasting longer than other flints, and being more certain in their fire. In 1837, Dr. James Mitchell visited Brandon, where he was informed that the French no longer made gun-flints, and that the Brandon makers were the only ones in the world. About 70 or 80 men were employed. The flint was obtained from a common about a mile south-east from the town. The chalk is within 6 feet of the surface. The men sink a shaft down about 6 feet; then proceed about 3 feet horizontally, and sink another shaft lower down into the chalk about the same depth of 6 feet, and sometimes they fall in with a floor of flint within this depth. They proceed again about 3 feet horizontally, and sink another shaft 6 feet; and so they proceed, going in some cases to the depth of about 30 feet. By making their shafts only about 6 feet deep, they are able to descend, and hand up the stone from one stage to another, without the aid of any machinery;

and although a windlass, rope, and bucket might save labour, they would require capital, which the poor men could not command. They pay a rent of 5*s.* to the parish for every cart-load, which is as much as three horses can draw. In the descent of about 30 feet they generally find three floors of flint, and sometimes four. At every floor they excavate horizontally for several yards, sometimes 20, below the chalk. The flint is in large blocks, which the men break into moderately-sized pieces, and hand them up from stage to stage.

Flint of the best quality, adapted to the making of gun-flints, is comparatively rare in France as well as in England. Dolomieu states that where twenty beds of flint were found lying one above another, only one or two of these would afford good flint. On the banks of the Cher flints were obtained by sinking shafts to the depth of 40 or 50 feet, from which horizontal galleries were driven through the only one good stratum met with. Dr. Mitchell was also informed that the gun-flint makers at Maidstone found only one stratum of flint fit for use in the quarries of Kent. This stratum lies under a stratum of green chalk, and is the only one which will not decompose. Fragments which have been exposed for fifty years to the air are as black as ever.

The English method of making gun-flints was very inferior to the French. Pieces were struck off the edges of a block of flint, and when it happened that they were of such a form as would answer, they were brought into shape. Such flints were unshapely in comparison of the present very elegant form of gun-flints; there was a great waste of material, and only a small number could be made in a given time. The improved method differs in some respects from the French, and, as the description contains a few interesting particulars, we will insert it here.

One man, called a *cracker*, is seated in a chair, with a thick piece of leather strapped to his left thigh, and over the leather he straps a thick piece of iron. He takes a large piece of flint-stone, and breaks it into pieces of about 2 lbs. each. He then takes one piece in his left hand, and, applying it to the plate of iron on his thigh, strikes out fragments at short distances from each other. He then strikes with his hammer on the parts of the edge of the flint which are now separated from the rest, and the effect of the blow, together with the reaction of the plate of iron on his thigh, causes a flake of about 3 or 4 inches in length to come off, there being on each side a conchoidal fracture. Of the flakes thus obtained, some are large, and others small. The man has before him three open casks, into one of which he drops the larger flakes, into the second the flakes of less size, and into the third the smallest flakes. Each cask goes to a separate workman, called a *napper*, who finishes them into flints, as *musket* flints, *carbine* flints, *horse-pistol* flints, *single barrel* flints, *double barrel* flints, and *pistol* flints. One cracker can keep three nappers employed. The napper has before him a block not unlike a butcher's block, upon which a piece of iron is nailed, from which rises a thin piece of iron, 3 inches in length and $\frac{1}{8}$th inch thick, brought to a coarse edge. The napper's hammer is a plate of steel, $\frac{1}{6}$th inch thick, fixed in a handle. He takes in his left hand a flake, lays it over the little anvil, and with his hammer breaks it into three or four flints: after which he decides which edge will be best for the flint, and from the other he chips a little off, and the whole is complete.

Dr. Mitchell says, "When we look at a gun-flint, and observe its elegant shape, and consider how admirably it is adapted for the purpose intended, we should be apt to think it had been ground into that shape with great labour and skill. Such, indeed, is the manner in which gun-flints, if we may so call them, are made in Germany from agates and conglomerates; but they are much less efficient, and more expensive."[1] During the war, the best musket-flints were sold for 42*s.* per thousand. In 1837, the price was from 7*s.* to 8*s.* Such are the particulars of a curious, and, at one time, a highly important manufacture, which may now be said to be quite extinct. Our chief object in giving all these details is to show how easily and how cheaply so difficult and refractory a material as flint may be made to assume the form and dimensions which the wants of the age dictate.

FLOOR-CLOTH, a durable covering for floors, bearing as little apparent relation to *cloth* as a finished oil-painting does to canvas. The custom of covering the floors of rooms and passages has now become almost universal, and while carpets supply the warmth and comfort necessary for the former, floor-cloths have been invented to bear the rougher usage of the latter. Floor-cloth is a cloth, or canvas, painted on both sides, the under side being plain, the upper side ornamented with a pattern. It is essential that the cloth used for this purpose be without seam; its manufacture, therefore, forms a distinct branch of trade: it is woven in very large pieces for this use alone. The pieces are from 18 to 24 feet in width, and are manufactured at looms adapted to this great width, and at which two men (one on each side) are employed in throwing the shuttle backwards and forwards. The length of the warp often exceeds 100 yards. Dundee, celebrated for its manufacture of sail-cloths, &c., is the seat of this trade.

The canvas is received at the floor-cloth manufactory in the form of bales, containing from 100 to 113 yards in length, and weighing about 5 cwt. each. One of these is opened, and from it is cut the quantity required to make a piece. This is done on the floor of the *drying-room*, whence the piece thus cut off is carried (wound on a wooden roller) to the *frame-room*. In this room a number of substantial wooden frames are set up, a few feet apart, and on these the canvas is to be stretched, preparatory to the painting. A space of a few feet occurs between every two frames, and this is occupied by a scaffolding of four tiers, any one of which may be reached by means of a ladder placed at one end of each frame. The roller containing the canvas is set up on end, and rests on a low carriage, which is wheeled along as the canvas is unwound. But the first step

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(1) Jameson's Edinburgh New Philosophical Journal, vol. xxii.

is, to bring it parallel with one of the upright ends of the frame, and make fast its edge by nailing it from top to bottom to the upright post. The unwinding of the canvas then proceeds, a temporary fastening being made to the top beam by means of a [illegible], or arrangement of hooks, preparatory to the subsequent equable straining of the immense surface.

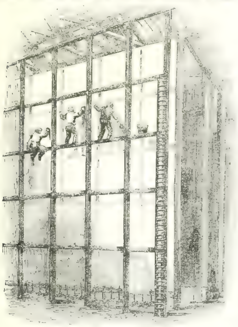

Fig. 967. THE FRAME ROOM.

When all the canvas is unrolled, the other end is also attached to the frame; but the whole yet remains hanging loosely, and has to be tightened by lengthening the frame by means of screws. The upper and lower horizontal edges have also to be secured to the beams, and stretched out in a similar manner. The whole at length becomes nearly as tight as the head of a drum, and if this be done in dry weather, and a change to wet suddenly take place, the tension is sometimes so much increased as to split the canvas; this arises from the natural property of the spiral fibres of flax to become shorter from moisture, and consequently, to make the canvas shrink.

In order to prepare this extensive surface for the reception of the paint, a weak solution of size is laid on with a brush, and while it is yet damp the canvas is well rubbed with pumice-stone. This softens down any irregularities, while the size fills up the interstices, and keeps the paint, which is afterwards applied, from penetrating too far, the effect of which would be to make the floor-cloth hard and brittle. This *size priming* and *pumice scouring* is carried on from the top of the frame downwards, one man applying the size, while two follow with the pumice-stones. The back surface of the cloth is primed first.

This first process being completed, and the surface dry, a coat of paint is applied, stiffer than that used in house painting, and containing little or no turpentine. It is first thrown on in dabs, with a short thick brush, shown in the man's left hand in Fig. 968, and afterwards spread with a steel trowel, Fig. 969, about 2 feet long, very elastic, and having the handle near one end. When a large surface has been gone over with considerable force, the trowel is held obliquely, so that its edge alone may act, and thus a large portion of the paint is scraped off again, and the high threads of the cloth become visible. But the paint has been thoroughly worked into the web of the cloth, filling up interstices, and making the surface level. The *trowel colour*, as it is called, is left to dry during from 10 to 14 days, according to the weather; a second and thinner coat is then smoothly laid on with the trowel, and when this is also dry, certain marks are made which shall enable the manufacturer at any time to identify the cloth as of his own make. This completes the operations for the under side of the canvas. But between the two coats of paint thus applied to the under side, the process is commenced on the upper side or face, by applying size and pumice-stone, as before. A trowel colour is also laid on, but when this is dry, the face is carefully pumiced, in order to get rid of the slightest lump or knot. Two more trowel colours are added with the use of the pumice-stone between each. A fourth coat laid on thinly with a brush, and called *brush colour*, forms the ground of the future pattern, and completes the floor-cloth, with the exception of the printing.

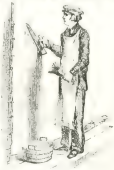

Fig. 968.

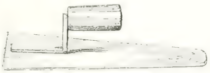

Fig. 969.

The series of operations thus briefly alluded to, occupies from two to three months, during which time, if the article be of the best quality, the canvas has increased in weight nearly fourfold; but if an inferior sort of floor-cloth be intended, then the number of coats and the weight will be proportionally less. The cloth is now to be removed from the frame on which all these operations have been carried on: this is done by running a sharp knife along the edges so as to detach it; it is then covered on the face with paper, rolled and hauled up into the printing room above by means of ropes and pulleys. The printing is performed on a flat long table, and the floor-cloth is drawn up and along its surface in portions as required. Wooden blocks, similar in principle to those used in wood engraving, are employed to stamp the pattern, but as the latter generally consists of several colours, a separate block is required for each colour. There are, therefore, as many separate printings as colours, and these are sometimes seven or eight in number.

In preparing a set of blocks for printing floor-cloths, an accurate coloured sketch of the design is first made on stout paper. A blank sheet of paper is then placed under this, and by means of a sharp point, all that portion of the device including one colour is marked upon the under sheet in a series of dots, or holes. This sheet being removed, another is placed under the pattern, and all the figures of another colour are pricked out in a similar manner. Thus, the pattern is dissected on as many sheets of paper as there are colours to be printed. This being completed, the several parts have to be transferred to the blocks. For this purpose one of the pricked sheets is fixed on the surface of a block, and a little powdered charcoal is dusted over it from a muslin bag, and dabbed upon the paper so as for it to penetrate the holes. A dotted line is thus made upon the block, which serves to guide the pencil of the engraver when the paper is removed, and enables him to draw the portion of the pattern required for that block. The same plan is pursued with other blocks, which are then ready for the engraver, who cuts away the wood and leaves the pattern in relief. When a solid mass of black or white occurs in the pattern, (as the squares employed to imitate marble,) it is sometimes filled in by hand, or the wood is cut into a series of narrow channels, crossing each other at right angles. These hold the ink, and produce the intended effect, whereas a large unbroken surface fails to take up the colour equally. Sometimes, brass wire is inserted to form a pattern, and then ground down level; but this makes the block inconveniently heavy.

The engraved portion of the block is of pear-tree wood; to prevent warping, this is fastened to two blocks of deal, glued and pressed together so as for the fibres of each to cross the other at right angles. The printing surface is about 18 inches square, and is soaked in oil while new, that it may take up the colour more readily. The cost of a block, including the engraving, varies from 2 to 4 guineas, so that in large establishments, where several thousand blocks are required, the value of this portion of the stock is great. The blocks not in use are carefully preserved in a room set apart for that purpose, and where a tolerably equal temperature is maintained throughout the year.

The printing of floor-cloth is thus conducted. On a table is placed a number of flat cushions, each about 3 feet square, consisting of a pad of flannel covered with smooth floor-cloth. By the side of each cushion stands a pot of colour, from which a boy called a *tearer*, or *tierer*, takes up a portion with a brush, and spreads it over the cushion, first passing his brush from top to bottom, and then across the cushion, till a shallow but equable bed of paint is prepared. Each cushion receives one colour only, and when the printing is in several colours, the boy has his full employ in keeping the cushions well supplied. A portion of floor-cloth being unwound and spread upon the printing table, a man hastily passes a steel scraper over it slightly to roughen the surface for receiving the colour, and a second follows with a hard scrubbing-brush for the same purpose. The printers follow next, their number agreeing with the number of colours to be printed. The first, holding his block by a handle attached to the back, as shown in Fig. 971, presses it down on the cushion to imbibe the desired colour, then takes it to the cloth, and carefully placing it at the right hand corner, holds it firmly, at the same time striking it several times with the handle of a heavy hammer, Fig. 972. He then lifts up the block, and a clear impression is left of a portion of the pattern in one colour only. Taking a fresh charge of the same colour, he makes a second impression by the side of the first, and so on in regular rows along the whole extent of the cloth upon the table, taking care to keep his squares perfectly true and even. When this first printer has advanced a little way, a second charges his block with a different colour, and begins precisely where his comrade did, delivering his portion of the pattern with a few strokes of the hammer, as before. After him follows a third, and as many more as may be required to form the most elaborate pattern. Thus the device is rapidly perfected, and the first printer, who is necessarily in advance of his comrades, has time to examine the work and to supply any flaws with paint of the proper colour, laid on with a camel's hair pencil.

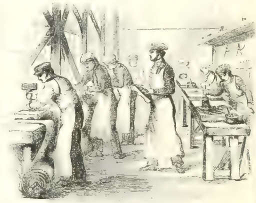
Fig. 970. PRINTING FLOOR-CLOTH.

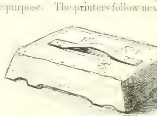
Fig. 971.

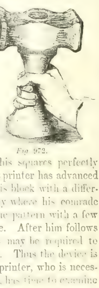
Fig. 972.

Suppose the pattern be in four colours, viz. black, white, and light green, on a dark green ground, as shown in the finished pattern, Fig. 973. The ground having been previously prepared, the printing is performed by three blocks in succession, one of which, Fig. 974, takes up and prints the white colour; Fig. 975 takes up and prints black, and Fig. 976 takes up and prints the light green colour. As the printing proceeds, the cloth is turned over and gradually descends through an opening in the floor to the drying-room, where it sometimes remains for months. The process can be hastened by the use of drying oils, but this makes the floor-cloth brittle. Narrow widths of floor-cloth for passages, stairs, &c. are first cut the required width, and then printed in the same manner as the wide, except that a space is left on each side for the border, which is put on with smaller blocks afterwards.[1]

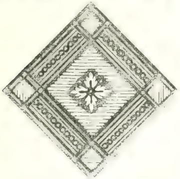
Fig. 973. THE FINISHED PATTERN.

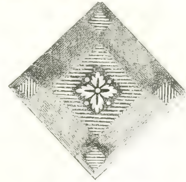
Fig. 974. THE WHITE PORTION.

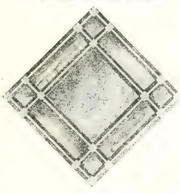
Fig. 975. THE BLACK PORTION.

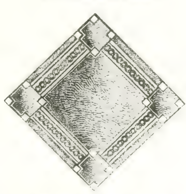
Fig. 976. THE LIGHT GREEN PORTION.

FLOORS and PARTITIONS. The term *floor* is derived from the Anglo-Saxon *flor*, (German *flur*,) and originally signified a field, or flat-spread surface.

The construction of floors presents less scope for ingenuity, and therefore possesses less interest, than the higher branches of framing and trussing, but is nevertheless well worthy of attention. The carpenter's art extends only to the provisions for strength and durability, as he does not enter on the subject of Inlaid work, Parquetage, or other modes of ornament. [See INLAYING.]

Floors are commonly distinguished as, 1. *Single-joisted*; 2. *Double*; and 3. *Framed*. In modern practice these three kinds may be regarded as generally applicable to areas of progressively increasing dimensions. In old work, floors of small surface were often made either double or framed, but as a general rule, modern artificers are only led by necessity to pass from a simple to a more complex form. Some curious specimens exist which can be classed under neither of these heads, but such are rather interesting for their ingenuity than valuable as examples for imitation.

(1.) *Single-joisted floors* are the most simple. Fig. 977 shows a section of this flooring, made parallel with the boarding. They have the planking or actual floor supported only by a single series of parallel timbers called *joists*, *a a*, or, collectively, the *naked flooring*. These rest upon *wall plates* built into the walls of the edifice, and are cogged down upon these plates in the manner shown in Fig. 988. The laths for supporting the ceiling are nailed to the under side of these joists.

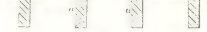

Fig. 977

As the strength and stiffness of a beam to resist transverse strain, increases much more with any given addition to its depth, than with an equal addition to its breadth, these joists are made very deep in proportion to their breadth or thickness. But this latter dimension should in no case be less than 2 inches, or the piece will be liable to injury from the nailing. In good substantial work, 12 inches apart from centre to centre is a proper distance for the joists, but this is often exceeded in slight and cheap erections.

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[1] We are indebted to Messrs. Smith & Baber, of Knightsbridge, for the illustrative sketches, and for most of the information contained in this article.

In all these constructions it is not sufficient to make the work so strong that it shall not *break*, but it must be made so strong that it shall not *bend* in any perceptible degree under the strain it has to bear. Therefore, in deciding on the dimensions of the timbers to be used in floorings, regard must be had to their sufficient stiffness, and not merely to their sufficient strength. Now the stiffness of a beam in supporting a transverse strain varies as $\frac{bd^3}{l^2}$ (C), where b is the breadth, d the depth, and l the length; and C is a constant quantity dependent on the kind of material employed, and determinable by actual experiment.

Hence, to find the proper depth for a common joist, when its length and breadth are given, we have $d = \sqrt[3]{\frac{l^2}{b}}$ (C), where b and d are measured in inches and l in feet. The value of (C) is then, for fir, 2·2; and for oak, 2·3. It is obvious that this equation may be used to determine any one of the measures b, d, or l when the other two are given.

When the length of the joists exceeds 8 feet, they must be *strutted* to prevent their tendency to turn over sideways. This is done by nailing cross pieces of wood between them, as shown on the right-hand of Fig. 980, or by simply driving short ends of plank between them. And in case the length of bearing exceeds 12 feet, there should be a row of struts at each four feet of the length of the joists.

Sometimes the joists cannot be carried through to the wall at one end, as, for example, when they come opposite to a fire-place, or to a staircase, then the short end is supported on a *trimmer*, *c*, Fig. 978, which is tenoned into the two adjacent through-joists. The joint for the ends of the trimmer is the *tusk tenon*. The long part of the tenon is usually carried quite through the joists, and pinned, or preferably wedged on the outside. (Fig. 978.) The two *trimming joists*, *f f*, into which this cross-piece is tenoned, are made a little thicker than the other joists in the proportion of $\frac{1}{8}$ inch additional thickness for each joist the trimmer has to sustain. The dimensions of the trimmers may be calculated by regarding them as binding joists.

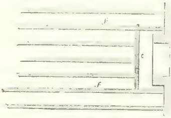

Fig. 978.

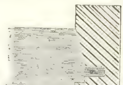

Fig. 979.

It should be observed that when the length of the joists exceeds 10 or 12 feet, it is very difficult to prevent cracks in the ceiling beneath. Hence, when a perfect ceiling is indispensable, a double or framed floor should be used for all areas exceeding 10 feet in their least dimension. In ordinary domestic buildings these cracks are less regarded, and therefore the use of the single-joisted floor is not so limited.

An improvement on the common arrangement (shown in section in Fig. 980,) is made by cutting each third or fourth joist rather deeper than the others, and using *ceiling joists*, *b*, which are notched upon these deep pieces, and nailed up to them. The ceiling laths are then nailed on these lower joists. Such a floor is but little deeper than one of the common form; it is much less pervious to sound, and the ceiling is less liable to be cracked. The rule for the strength of ceiling joists is given lower down.

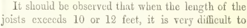

Fig. 980.

(2.) The *Double floor* is applicable in cases when long timber cannot be obtained in sufficient quantity for single joisting, or when it is desirable to divide the span so as to ensure a perfect ceiling. Fig. 981 gives a section of double floor.

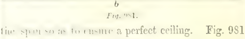

Fig. 981.

Stronger timbers, named *Binding joists*, *c c*, are then laid across from wall to wall at about 6 feet asunder; and the common joists, which now assume the appellation of *Bridging joists*, *a a*, are notched down upon these as in the figure; the distance asunder of these bridging joists remaining the same as before. The ceiling joists b are nailed up to the under-surface of the binders, or are mortised into their sides.

The formula for finding the dimensions of binding joists is, as before, $d = \sqrt[3]{\frac{l^2}{b}}$ (C), here (C) being 3·42 for fir, and 3·53 for oak. This is supposing that the binders are not more than from 4 to 6 feet apart.

In all these cases, the ceiling joists, to which the laths for supporting the plaster are nailed, need be no thicker than is sufficient for giving them a good hold on the nails. The equation $d = \sqrt[3]{\frac{l}{b}} \times 0{\cdot}64$ will give the relative dimensions for fir. For oak, the constant 0·67 must be taken. Their breadth rarely exceeds $1\frac{1}{2}$ to 2 inches.

(3.) The third, or *Framed floor*, is applicable when very large surfaces are to be floored with great accuracy. Strong balks of timber, termed *girders*, *d d*, Fig. 982, are laid across at distances of from 8 to 10 feet asunder, and the binding joists *c* are tenoned into these main pieces. On the binders the bridging joists *a*, ceiling joists *b b*, and flooring are supported as before described. The spaces divided off by the girders are named *Bays*. If included between two girders, it is a *Case-bay;* when between a girder and the wall, it is a *Tail-bay*. Thus, also, the work included in each of these spaces is called a *Bay of joisting*.

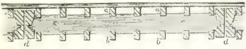

Fig 982.

The same equation is used to determine the dimensions of girders, as of binding or bridging joists, but the value of *c* is now increased to 1·2 for fir, and 1·31 for oak. The girders are let into the walls for a depth of 10 or 12 inches, and rest on strong pieces of timber, named *templates*, which serve to distribute the pressure. In order also to prevent as far as possible the decay of the ends of the girder, these should not be built close into the wall, but about an inch of air-space should be left all round them. Fig. 982 gives a section of a framed floor made parallel to the plane of the binding joists, and therefore across the girders.

It is a common practice to saw the balks of timber intended for girders down the middle, and to bolt the two halves together, back to back, keeping them an inch or two apart by small pieces of wood placed vertically between them. This method is shown in the figure. Several advantages arise from this practice: it enables the heart of the timber to be examined as to its perfect soundness; it allows greater freedom for the passage of air around and between the pieces, and it gives the workman the opportunity of equalizing the strength of the two ends of his girder by turning one half end for end with the other.

Girders for long bearings should always be made as deep as possible; but where it is not practicable to sacrifice sufficient depth in the floor for this purpose, the girders must be made considerably wider, and should be placed nearer together.

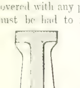

Fig. 983.

When the span of the floor is greater than can be covered with any piece of timber attainable, recourse must be had to iron, or else the girders must be *trussed*. Cast-iron girders are now readily obtained in almost all places. They are made of the section shown in Fig. 983, and as this metal yields much more easily to extension than to compression, the lower flange (the part extended by a weight placed above) should have six times the sectional area of the upper or compressed flange. In computing the strength of such a casting, it is usual only to reckon on the strength of this lower flange, assuming, from the nature of the material, that if this be made strong enough to resist the extending force, the top will certainly have sufficient substance to support the compression. Hence the following rule for the strength of cast-iron beams:—Multiply the area of the lower flange in square inches by the depth of the beam in inches, and divide by the length in feet. This product multiplied by 2·166, gives the breaking weight at the centre (or half the breaking weight if distributed equally over the whole length), in tons. From one-third to two-fifths of this weight is the limit of safety in practice. The binding joists in such girders rest on the lower flange, being confined between small bracket-shaped pieces cast in the angle between the vertical rib and lower flange.

The immense strength obtainable by the use of wrought-iron in thin plates, shows that this material might be advantageously used in many cases to span considerable widths.[1]

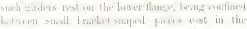

Fig. 984.

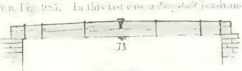

Fig. 985.

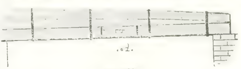

Fig. 986.

But in cases where metal girders are not applicable, a built-up wooden girder may be used. This may be made by connecting a balk of some hard rigid wood with a straight-grained tough timber, using the former, of course, for the upper or compressed part, and the latter for the lower or extended part. They are prevented from sliding on one another, either by keys, as in A, Fig. 984, or by being tabled together, as in B, Fig. 985. In this last case a *key-bolt* is advantageously added to tighten the joints, as in the figure. Bolts may be used to bring the pieces together, or preferably the upper piece may be tapered from the middle to each end, and the two drawn together by hoops driven on. Another mode of building up a beam, is that of cambering or curving it, and holding it in this position by bolts or straps. Fig. 986 shows the half-length of a cambered beam thus applied at the upper part of a built-up girder. If it is necessary to use more than a single length of timber, the upper beam may have a plain butt-joint at any convenient part of the span, but the lower beam, if jointing be unavoidable, should have its scarf near to one end of the span, and by no means at or near the middle, where the greatest strain is exerted. For the scarf the joint shown at Fig. 192, Art. CARPENTRY, may be used.

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[1] The account of the Britannia and Conway Tubular Bridges by Edwin Clark, Esq. C.E., gives a mass of most valuable information as to the [illegible] and strengths of most forms of metal [illegible], 1850.

A beam is sometimes trussed with iron, as in Fig. 987, but this method is not recommended in practice

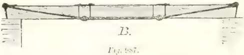

Fig. 987.

It requires great accuracy of fitting, and is liable to have all its efficiency destroyed by small changes of dimension in its parts.

The cost of flooring is estimated by the *square* of 100 square feet.

The following general principles apply to all kinds of flooring. The bearing timbers which sustain the weight, should, if possible, be laid across the narrowest way of the room. In a single-joisted floor, the joists should run in this direction, but in a double floor, the binding joists are the bearing pieces, and should be laid this way. In a framed floor, the girders become the bearing pieces, and should then have this advantage given them. In a square room, of course, the directions are immaterial.

With any given quantity of timber, the single-joisted floor has been proved, by direct experiment, to be the strongest form of any, and it also possesses the advantages of requiring fewer joints, and of distributing the weight borne more directly and generally over the walls. Against these merits, are to be laid the difficulty, when the span is great, of procuring a sufficiency of long timber, as well as the liability to disfigurements from partial strains of heavy goods or furniture, and finally, the facility with which sounds are transmitted unless some special means of prevention be adopted.

Flooring-timbers should never be laid obliquely, but should be placed parallel to one or other wall of the room. Girders should never be laid over spaces, such as doors or windows. If, however, this position be unavoidable, the templates should be strong and long enough to throw the weight well on the piers.

When first laid, the floor ought to be rather high in the centre, to allow for settling at the joints. When all is settled, the floor should be perfectly level. If it is cambered up, it must evidently exert a thrust outward on the walls. If so weak as to sink down in the centre, it as evidently tends to pull the wall-plates inward. In either case, the ceiling beneath will be cracked and disfigured. It is only when perfectly level that the floor exerts no thrust or strain on the walls.

Common cheap floors are often laid with boards of from 7 to 9 inches in width, but the best floors have their boards or battens not more than from 3 to 5 inches wide. These last do not, of course, show the shrinkage of the stuff, as the ordinary constructions do in too many cases.

In all the equations for dimensions, the constant for oak is higher than that for fir, on account of the liability of this timber to be cross-grained, and thus to become weakened in cutting.

Of extraordinary floors the one most worth mentioning appears to be that applied in Amsterdam to a room 60 feet square. This had neither joists nor girders, but consisted merely of three thicknesses of 1½-inch boards laid one on the other and securely nailed together, and to very strong wall-plates. The lowest layer ran diagonally from corner to corner, the second layer also went diagonally, but from the opposite corners, so as to cross the first thickness at right angles. The upper set ran in the usual way from side to side. The floor thus became a strong thin plate of wood, supported and strained all round its edges.

Short joists may also be used by being tenoned one into the other, and made to rest at the other end on the wall-plates, as shown in Fig. 988.

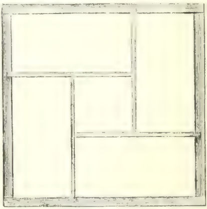

Fig. 988.

Partitions may be advantageously considered in this place. Their construction comes under the charge of the carpenter, and is usually proceeded with at the same time as that of the floors. Indeed, the constructions of the two are in some respects connected.

The term partition is restricted to those internal divisions of a building, into the essential constructive part of which, timber enters in a greater or less degree. These divisions either consist of a framework of wood simply covered with laths and plastered, or the spaces in the wooden frames are filled in with brickwork. In the first case it is said to be a *quarter partition*, in the last case it is called a *brick-nogging partition*.

Partitions are sometimes constructed so as to be dependent on or connected with the floor above or below, and in other cases they are made wholly independent of these floors, and self-supporting. One of the first kind need consist only of upright pieces of timber of a width sufficient to bear nailing, (say from $1\frac{1}{2}$ to 2 inches,) and of a depth suitable to the intended thickness of the partition, tenoned into a horizontal sill at top and bottom, and stiffened by struts placed between them. The distance between these uprights may be from nine inches to a foot. The laths are nailed upon these pieces, and covered with plaster. Such a partition as this, if it be not supported continuously up from the bottom of the building, should rather be strapped from the floor or truss above it, than allowed to bear on the floor beneath. The weight is then not unduly thrown on the joists beneath, with the certainty of cracking the ceiling, nor does the partition become liable, by its settlement, to tear away from the ceiling of its own room, and thus produce unsightly cracks in the plaster and cornice. But though it is often practicable to obtain a continuous support up from below, it is by no means desirable to use it, as any unequal settlement of the main walls, and of the internal division, must crack the partition. Therefore it is better in all cases to make the partition self-supporting, and dependent only on the two main walls. The partition becomes in fact a very deep truss

If there is no doorway to be made through from one room to the other, the ordinary king-post truss may be used for short spans. When the span is considerable, or when doorways are to be made through the partition, the truss may assume the queen-post form as in Fig. 989. In Fig. 990 is shown a form of partition adapted for two doorways. The sill or tie must be either carried under the flooring, as in Fig. 989, or may be carried over the head of the doorway, as in Fig. 990.

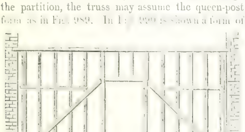
Fig. 989.

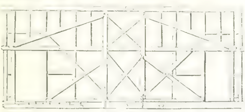
Fig. 990.

The principals of the truss (which in partition-work are called *braces*) should be inclined at an angle of about 40° to the horizon. This will, therefore, to a great extent, determine the form of truss to be employed. The nature of the strains on the several pieces may be determined by the rules already given in the Article Carpentry. In deciding on the substance of the timbers, due regard must, of course, be had to the weight to be borne by the truss, as in some cases the partition has not only to support itself, but also a floor, and perhaps other partitions above.

Any small shrinkage of timber or slipping at joints, will do more harm in partition-work than the same amount of yielding in almost any other part of a building, as such failures are sure to be attended by cracked walls and ceilings. Partitions should therefore be built of well-seasoned timber, the joints carefully drawn and fitted, and the whole allowed to stand in its permanent place some time before it is lathed and plastered. Settlements can then be remedied if serious, or if not, the timbers having once taken their bearings, may be safely covered.

In a brick-nogging partition, the wood pieces (called *nogging-pieces*) should project a little on both sides beyond the brickwork, to allow of the laths being nailed to them. When the thinness of a partition is not so much an object as its strength and impenetrability to sound, it is better to nail the uprights which take the laths on the outsides of the main truss, instead of cutting them so as to fit in between the timbers of this truss. This plan takes rather more timber, and makes the partition thicker, but it renders it much stronger, and also far less pervious to sound.

Partitions are measured like floors, by the square.

In computing the required strength of the pieces in a partition, the following may be taken as the weights of the parts to be supported:—

A square of common quarter partition . .	1,500 to 2,000 lbs.
A square of single joisted flooring	1,[illegible] to 2,000 ,,
A square of framed flooring, with counter flooring	2,500 to [illegible] ,,

It is a safe plan to use the highest numbers when the truss is of considerable length, and to employ the lower numbers when the span over which the truss is to be carried is short.

FLOSS-SILK, a name applied to the portions of ravelled silk broken off in the filature of the cocoons of the silk-worm. It is carded like cotton or wool, and spun into a soft coarse yarn or thread, with which common silk fabrics are made. See Silk.

FLOUR, see Bread.

FLOWERS of sulphur, a term applied to sublimed Sulphur. The old chemists used also to speak of *flowers of benzoin, flowers of zinc*, &c., from the resemblance of these sublimed substances to the dust or pollen of flowers.

FLOWERS, ARTIFICIAL. The manufacture of artificial flowers, first brought to a high degree of excellence by the Italians, and now most successfully prosecuted by the French and English, is one of no small importance considering the amount of skill and labour which it brings into requisition. The perfection to which this art has been carried was illustrated in a remarkable manner in the Great Exhibition. The imitations of vegetable nature, there shown in its blooming freshness and in its decay, were perfectly wonderful, embracing the most difficult and complicated forms, as well as the most simple. The grotesquely varied shapes and delicate colourings of Orchids and other tropical plants, were as successfully imitated as the familiar forms of rose, lily, and mignonette. So accurate, indeed, were the copies of rare and fragile plants, that we have the testimony of a professor of botany to their value in reference to his science.

Such being the successful results of this manufacture, it must no longer be considered as a mere auxiliary to the toilet. It is worthy of a higher rank than has yet been accorded to it; and the ingenious processes connected with it are well deserving of notice. The first attempt at making artificial flowers among civilized nations, was by twisting ribbons of different colours somewhat into the shape of flowers, and fastening them to wire stems. This yielded to the use of feathers, which were far more elegant, but could not always be made to imitate in colour the flowers which they represented, there being considerable difficulty in getting them to take the dyes. Where the plumage of birds is of great brilliancy, the natural colours admirably answer the purpose, and do not fade or lose their resplendent hues. Thus in South America, the savages have long known how to fabricate beautiful artificial flowers from such plumage. In Italy the cocoons of silkworms are often used, and have a soft and velvety appearance, while they take a brilliant dye. In France the finest cambric is the chief material, while wax is also largely employed. The arrangement of the workshop, and the variety and use of tools, where flower-making is practised on a large scale, are as follows:—

A large and well-lighted room, which has the means of warmth in winter, is selected, and along its whole extent is placed a table, similar to the writing tables used in schools, where the work-people may have a good light as long as possible. This table is fitted with drawers containing numerous compartments, arranged so as to receive and keep separate the small parts of flowers, such as petals, stalks, minute blossoms, catkins, buds, leaves not mounted on their stalks, and all other parts not fit to be placed among more finished specimens. It is desirable that the table be covered with oilcloth, so that it may be frequently cleansed, by washing, from the stains of the different colours employed. Along the whole extent of this table are placed flower-holders, that is, light frames with horizontal iron wires, to which the flowers, when attached to their stalks, are suspended by merely crooking the end of the stalk, and hanging it on the wire. Sometimes tightly strained packthread is used instead of wire. Figs. 991 and 992 represent two forms of flower-holder; in both cases the frame is fixed to the table. Along the table are also ranged bobbin-holders in considerable numbers, not unlike those used by weavers. The bobbin-holder is a rod of iron, Fig. 993, about six inches high, fixed in a massive leaden or wooden base. On this rod is threaded a large bobbin, on which is wound a quantity of silk or wool. On its summit may be fixed a nut to prevent the bobbin when in rapid motion from whirling off the rod, but this is often omitted. Ladies who work for their pleasure, frequently have this bobbin-holder made in an ornamental form, the base being covered with bas-reliefs, and the nut at the top taking the form of an arrow, a blossom, &c. But the more simple and free from ornament, the better is the holder for use, any unnecessary projections only acting as so many means of entangling the silk.

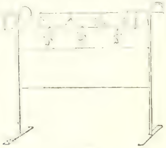
Fig. 991.

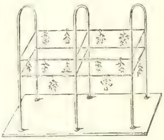
Fig. 992.

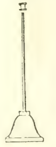
Fig. 993.

The flower-maker does not take up flowers or their parts with the fingers, but with pincers of the simplest description, Fig. 994, which are incessantly in use. With these the smallest parts of the flower can be seized, and disposed in their proper places, raised, depressed, turned about and adjusted according to the taste of the artist, and her appreciation of natural forms. It is with the pincers also that any little contortions of the extremities of petals, and irregularities in their form and in the arrangement of stamens, are copied. The proper length of this tool is about five inches. Each workwoman brings one for her own use, and keeps it close at hand. Dressing-frames of various sizes form another part of the furniture of the work-room. On these are stretched the materials which are gummed and dyed. A dressing-frame, Fig. 995, consists of two uprights of hard wood, with two cross pieces of the same, capable of adjustment. The frame is fitted with crooks for the attachment of the material, or with a band of coarse canvas to which the material can be sewn. These frames have

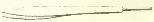
Fig 994.

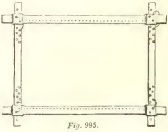
Fig. 995.

no feet, and are fitted sometimes against a wall, sometimes upon a chair. When covered with the material, they are hung up against the wall by one of the cross pieces, until it is time to dismount them.

There are also various useful implements, called by the work-people "irons," for cutting out petals, calyxes, and bracts, and for giving to leaves those various serrated and other forms, which produce such wonderful variety in foliage. These cutting tools, two of which are shown in Figs. 996 and 997, are of iron, with a hollow handle, flat at its upper extremity, that the hammer may be readily applied. They are about four or five inches long, and of numerous sizes and varieties. That they may cut rapidly and clearly, the edges are occasionally rubbed with dry soap. When a leaf becomes attached to the interior, and cannot be shaken out, a little ring of wire, Fig. 998, is introduced in a hole, *j*, Fig. 997, left for that purpose to disengage it. The material is doubled several times under the cutter, so that several petals or leaves may be cut out at once. The block on which the leaves are cut out is rather a complicated affair. It is placed near a window, and as far as possible from the workers, that the blows of the hammer may not interfere with their employment. Sometimes it consists of a very stout framework of timber, on which is placed a mattress of straw to deaden the blows, and upon this mattress a thick smooth piece of lead, forming a square table, Fig. 999. In some cases a solid block of timber is used, a portion of the trunk of a tree taken near the root, and on this the mattress and the leaden table are placed. The hammers used at this work are short and heavy; one is especially adapted for smoothing the surface of the lead when it becomes indented all over by the blows of the workman.

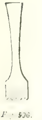
Fig. 996.

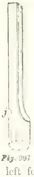

Fig. 997

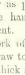
Fig. 998.

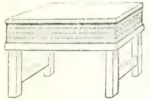
Fig. 999.

The cutting out of the leaves and petals is only a preliminary operation to the more perfect imitation of nature: the leaves must next be gauffered to represent the veins, the folds, and the endless touches and indentations which are found in the natural plant. Gauffering is executed in two ways, the first and simplest being that which merely gives the hollow form to the petals of roses, cherry-blossoms, peach, hawthorn, and numerous other flowers which preserve, until the period of decay, somewhat of the form of a bud, all the petals beautifully curving inwards. To imitate these, the gauffering tools are simple polished balls of iron fixed on iron rods, with a wooden handle attached, as shown in Fig. 1000. The balls are of various sizes, from a pin's head upwards, to adapt them to the minute blossoms of such flowers as the forget-me-not, which require only the slightest degree of curvature, and to the large flowers of camellia, dahlia, mallow, &c., where the curvature is often very great. These balls are made slightly warm, so as to fix the forms decidedly, without effacing the colours. The petals are placed on a cushion, and the iron is pressed against them. But curvature alone is not sufficient: there is, in many petals, a decided fold or plait up the centre, springing from the point where it is attached to the germen. This fold can be obtained by the use of a prism-shaped iron, Fig. 1001. Conical, cylindrical, and hooked irons, Figs. 1002, 1003, are also useful to imitate the various minutiae of the blossoms. A cushion near each artist serves as a rest to the gauffering irons, which must be preserved from the least taint of dust, seeing that they are applied to the most delicately-beautiful portions of the flower. The veins and curves of leaves are given by gauffers composed of two distinct parts, on each of which is severally moulded in copper, the upper and under surface of the leaf, as shown in Fig. 1004. Sometimes, one part is of iron, the other of copper. It is necessary to have a very large assortment of these gauffers; in fact, they should correspond in number with the cutting-irons by which the forms of leaves are punched out. The leaf or leaves being inserted in the gauffer, a powerful pressure is given to stamp the desired form. This is accomplished either by means of a heavy iron pressed on the lid, or by two or three smart blows of a hammer, or, better still, by the uniform action of a press, such as is shown in Fig. 1005. Besides the above articles, the workshop is provided with an abundance of boxes, scissors large and small, for cutting wire, as well as textile fabrics, camels' hair pencils, sponges, canvas-bags, &c., that everything likely to be needed by the work-people may be immediately at hand.

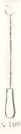
Fig. 1000

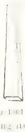
Fig. 1001.

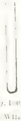
Fig. 1002.

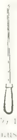
Fig. 1003

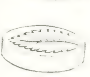
Fig. 1004.

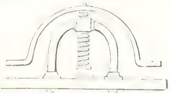
Fig. 1005.

The material of which flowers are made is, first and best, (as already stated,) French cambric, but a great quantity of Scotch cambric, jaconet, and even fine calico, are also used. For some descriptions of flowers, clear muslin, crape, and gauze, are wanted; and for some very thick petals, satin and velvet are necessary. These materials are provided in various colours, as well as in white, but fresh tints have frequently to be given. These are laid on with a sponge, or a camels'-hair pencil, or the petal is dipped in colour: a quantity of green taffeta should always be at hand for leaves. The colouring matters used in dyeing the material for the petals are as follows. For red, in its various shades, *Brazil wood* is largely used, also carmine, lake, and carthamus. The best way of treating Brazil wood is to macerate it cold in alcohol for several days; a little salt of tartar, potash, or soap, will make this colour pass into purple; a little alum gives it a fine crimson-red, and an acid will make it pass into yellow, of which the shade is deeper according to the quantity employed. Carmine is better in lumps than in powder; diffused in pure water, it gives rose-colour; a little salt of tartar brightens the tint. Carthamus is dissolved cold in alcohol; heat, as well as the alkalies, causes it to pass to orange. The acids render it of a lively and pale red; a very delicate flesh-colour is obtained by rinsing the material coloured with carthamus, in slightly-soapy water. Blue colours are prepared by means of indigo, or Prussian-blue. Sometimes balls of common blue are used, steeped in water. Indigo is first dissolved in sulphuric acid. This is then diluted with water, and powdered chalk or whitening is added until effervescence ceases. The liquor is afterwards decanted off, and the sediment, when washed, gives a paler colour. Greater intensity is given to indigo by adding a little potash. Yellow colours are given by turmeric dissolved in spirits of wine, by saffron, chrome-yellow, &c. Green colours are obtained by mixtures of blue and yellow; violets, by mixtures of red and blue, and by archil and a blue bath; lilacs, by archil only.

The method of making a rose will give a good idea of the manufacture in general. First of all the petals are cut out from the finest and most beautiful cambric. The pattern-shapes must be of different sizes, because in the same rose, the petals are never equal: a good assortment of patterns enables the artist the better to imitate the variety of nature. When the petals are thus prepared, they have to be dyed in a bath of carmine in alkaline water. For this purpose, they are held separately by means of pincers, and dipped first in the bath, and then into pure water, to give them that delicacy of tint which is characteristic of the rose. But as the colour of the petal usually deepens towards the centre, a tint is there laid on with the pencil, while a drop of water is laid on the point of insertion of the petal, to make the colour there fade off, as it does in nature, to white. If the right tint is not given at first, the processes are repeated: any slight imperfection, such as is seen in the petals of most living flowers, being also accurately imitated with the pencil. The taffeta employed in making leaves, is dyed of the proper green in the piece before cutting out. It is then stretched out to dry, and afterwards further prepared with gum-arabic on one side, to represent the glossy upper surface of leaves, and with starch on the other, to give the velvety appearance of the under side. This preparation, coloured to suit the exact shade to be given to the leaf, must be just of the proper consistence, making the leaf neither too stiff nor too limp, while it gives the proper kind of under surface. Where the leaf requires a marked degree of this velvet texture, it is given by the nap of cloth reduced to fine powder, and properly tinted. A little gum is lightly passed over the surface, and when partly dry, this powder is dusted over it, the superfluous portion being shaken off. These preparations having been completed, it yet remains to give to the leaves after they are cut out, the appearance of nature, by representing the veins and indentations which they always exhibit. For this purpose various gauffering-tools are made use of.

The material for the leaflets of the calyx in roses, is subjected to another process immediately on coming out of the dye, in order to preserve the firmness which it is necessary the calyx should have. To this end, the taffeta while still damp is impregnated with coloured starch on both sides, and stretched on the drying-frame: when perfectly dry, the leaflets are cut out according to pattern. Buds are made also of taffeta, or if partially open, they are made of white kid tinted of a suitable colour, stuffed with cotton, or crumb of bread, and tied firmly with silk to slender wires. The stamens are prepared by attaching to a little knot of worsted a sufficient quantity of ends of silk to form the heart of the flower. These ends of silk, cut to the proper length, are then stiffened in kid jelly, and when dry, the extremities are slightly moistened with gum-arabic and dipped in a preparation of wheaten flour, coloured yellow, to represent the pollen. Each thread takes up its separate grain and is left to dry. The heart of the flower being thus prepared, and fixed to a stem of wire, the smaller petals are arranged round it, and fixed by paste at their points. The larger petals succeed, some of which are hollowed or wrinkled, while constant care is taken to give them a natural appearance in disposing them around the centre. The calyx comes next, and encloses the ends of all the petals. It is fixed with paste, and surrounded with more or less of cotton thread, which also generally encloses one or more wires attached to that which bears the heart of the flower, and forming the germ. The whole is covered with silver-paper tinted green. The leaves are mounted on copper wire, and are arranged on the stem in the order which nature teaches, the covering of cotton and tissue-paper hiding the joints.

In addition to the manufacture of flowers intended as closely as possible to represent their living models, there is a large branch of the art in which the aim seems to be to depart from nature as far as possible. These *fancy flowers* are the fruit of the artist's peculiar taste, and are therefore as impossible to describe, as we sincerely wish they were impossible to execute. There are also flowers of natural forms, but of unnatural colours, being made to assume mourning hues to suit the circumstances of their wearers. There are also gold and silver flowers, more resplendent, but equally unnatural. Of these, sometimes the stamens and pistils alone are metallic; sometimes the petals are gilded, and sometimes the leaves and fruit glitter in the same precious metal. An easy method of applying the gilt in any device or form, is to prepare a cement which shall fix it to the cambric, paper, or other material. (this cement may be honey and gum arabic boiled in beer,) and then to moisten with it the surface, placing thereon rather more gold-leaf than is necessary to cover it, pressing it down with a cotton rubber, and when it is dry, rubbing off the superfluous gilding with the same.

Flowers are also made in chenille, but do not pretend to an accurate imitation of nature. There are two or three methods of making them, the simplest being to represent merely the shapes of flowers; for instance, apple-blossoms, represented by small loops of pink chenille arranged round a centre. Another method is, to make out the distinct petals, by rows of chenille placed close together. A third and prettier method, is that of uniting chenille with ordinary flower-making. Flowers made of feathers may be extremely rich and brilliant in their effect, as was proved by the beautiful bouquets in the Great Exhibition, and as may be observed in the flowers made of humming-birds' plumage in Mr. Gould's collection in the Zoological Gardens Regent's Park. Yet ordinarily feather-flowers are more difficult than satisfactory, and there are very few of our own familiar flowers that can be successfully copied by them. One of the best imitations is that of the wild clematis when adorned as it is in autumn with its plumed seeds. These can be admirably imitated in white marabout feathers. Some of the most available feathers for flower making, are those found under the wings of young pigeons.

The manufacture of wax flowers is carried on by using the purest virgin wax, entirely freed from all extraneous matters. Wax that is either granular or friable, must be rejected. It is generally melted in vessels of tinned iron, copper, or earthenware. To render it ductile, fine Venice turpentine, white, pure, and of an agreeable odour, is added. The mixture is constantly stirred with a glass or wooden spatula. All contact with iron must be avoided, and if the vessels are of that material, they must be well and carefully tinned. When stiff leaves are to be executed, two parts of spermaceti are added to eight parts of wax, to give transparency. Much care and tact are needed in colouring the wax. The colours being in fine powder, are made into a paste by adding little by little of essence of citron or lavender. When the trituration is perfect, this paste is mixed with melted wax, stirring rapidly all the while; and while the mass is still liquid, it is poured into moulds of pasteboard, or tinned iron, of the shape of tablets, and is then ready for use. Sometimes it is passed through fine muslin as it flows into the moulds. Another method is, to tie up the colour in a muslin bag, and wave it about amongst the molten wax until the desired tint is obtained. To combine colours, it is only necessary to have two or three bags containing different colours, and to employ as much of each as shall have the desired effect. These bags, far from being spoiled by dipping in wax already containing other shades, have only to be rinsed in pure water to fit them for colouring other wax. The colours most in use in wax flower-making, are pure forms of white-lead, vermilion, lake, and carmine, ultramarine, cobalt, indigo, and Prussian blue, chrome, Naples yellow, and yellow ochre. Greens and violets are chiefly made from mixtures of the above.

The wax being prepared, the manufacture of flowers is carried on in two ways. The first consists in steeping in liquid wax little wooden moulds rinsed with water, around which the wax forms in a thin layer, so as to take the form of the mould, and thus to present, when detached from it, the appearance of the whole or part of a flower. In this way lilac and other simple blossoms are obtained with much rapidity. The branches are also executed with wax softened by heat, and moulded with the fingers round a thread of wire. As for leaves and petals, they are cut out of sheets of coloured wax of the proper thickness. These sheets are glossy on one side, and velvety on the other. To express the veining of leaves, they are placed in moistened moulds, and pressed with the thumb sufficiently to get the impression, which is accurately copied from nature. The petals are made to adhere simply by pressure; the leaves are placed on a little footstalk, and the latter fastened to the stem. The manner of procuring moulds for the accurate imitation of leaves is as follows:—A natural leaf of the plant it is wished to imitate, is spread out on a flat surface of marble, for example. It is lightly but equally greased with olive oil, and surrounded with a wall of wax, which must not touch it. Then into a small vessel containing a few spoonsful of water, a few pinches of plaster of Paris are to be thrown, and briskly stirred till the liquid has the consistence of thick cream. This is poured over the leaf, and left till it is well hardened. It is then lifted up and the leaf detached, when it will be seen that the plaster has taken a perfect impression of every vein and indentation. Such moulds are rendered far more durable if they are impregnated while warm with drying oil. This gives them greater solidity, and prevents their crumbling from frequent immersion in water. It is necessary to impress strongly on all amateur wax flower-makers, the necessity for having all tools and moulds completely moistened with water, otherwise the wax will be constantly adhering, and preventing neatness of workmanship.

The variety of the materials used in artificial flower-making, was displayed to an amusing extent in the Great Exhibition. In addition to the really beautiful and artistic productions already noticed, and to the elegant flowers constructed of palm-leaves, of straw, and of shells, as well as of all the materials named in this paper, there were flowers fabricated in human hair, in chocolate, in soap, in wood, marble, porcelain, common earthenware and other unpromising materials

FLUE, see CHIMNEY.

FLUID, see HYDROSTATICS and HYDRAULICS.

FLUIDITY, see HEAT.

FLUOR SPAR. The word *fluor* is derived from the Latin *fluo*, to flow, in allusion to the important use of this spar as a flux. The Germans also name it *fluss-spath*. Its chemical name is *fluoride of calcium*. It is found in great beauty and abundance in England, and especially in Derbyshire, where it is commonly called *Blue John*. It is usually found in cubic crystals, which admit of being easily cleaved into octohedra and tetrahedra by splitting it in the direction of its solid angles, as in Fig. 1046, which shows the octohedron resulting from the cube.[1] The colours of fluor spar are various: the spar is found perfectly pellucid and transparent; also white, grey, and with various shades of blue, green, red, yellow, and purple. Its sp. gr. is 3. When reduced to small fragments and heated, fluor spar emits a phosphorescent light: the dark-blue variety exhibits a beautiful pale-green light, strong enough to be seen by day, but best seen in a dark room: the slightly-fetid variety shines with a purple tint; and one variety, which shines with a very brilliant green light, is on this account termed *chlorophane*. This phosphorescent property may be exhibited by sprinkling the crushed spar upon a hot shovel in a dark room, or by heating the spar in a platinum spoon over a spirit lamp. *Compact fluor* is harder than common fluor, and is sometimes granular in texture. That which is found at Stolberg in the Hartz is of a fine sky-blue colour, when first raised, but shortly, by exposure, becomes perfectly white. Indeed, the nature of the colouring matter of the blue and green spar is not understood. The workmen at Castleton, who make ornaments out of the Blue John, often find the colour so intense that the articles cannot be wrought thin enough to show it: they therefore gradually heat the stone in an oven until it is nearly red-hot, when the blue changes to an amethystine colour. By continuing the heat the colour entirely disappears. There is also an *earthy fluor*, which exhibits a friable texture.

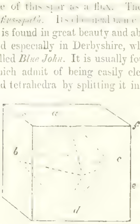

Fig. 1046.

The deep blue and purple varieties of fluor, found only at Castleton in Derbyshire, admit of being turned into vases, pateræ, and other ornaments. The stone is first roughed out with a point and mallet: then heated until it will fuse yellow resin, which is applied all over it: this penetrates about $\frac{1}{8}$ inch, and serves to hold the crystals together. It is next rough-turned, and a little hollowed; again heated, and resined and turned still more into form: it is next bound round with a thin wire, and again resined. These processes are continued until the spar is thin enough to show the colours: it is then resined for the last time, and polished. The only tool used is the steel point. The manufacture is a difficult one, since the spar, being an aggregation of crystals, all having a fourfold cleavage, the laminæ easily split and separate. Few, even of the best workmen, can turn very thin hollow articles.

FLUORINE, an elementary substance, (F. 19.) which has never been isolated in a state fit for examination. Compounds containing it can be decomposed without difficulty, and the fluorine transferred from one body to another; but so great is its affinity for the metals and for silicon, a component of glass, that in passing from one body it combines with the vessel containing it or one of its constituents. It is, however, from certain results that have been obtained, supposed to be gaseous, and, like chlorine, to possess colour. A compound of hydrogen and fluorine, hydrofluoric acid, has been used for etching on glass. By heating powdered fluor spar with concentrated sulphuric acid in a platinum retort, with a receiver of the same metal kept quite cold, a very volatile colourless liquid is obtained which emits copious white suffocating fumes in air. This is the anhydrous acid: it unites with water with much violence, and the dilute solution acts on glass with great ease. Dropped upon the skin, it is said to produce deep and malignant ulcers. For etching on glass the acid may be prepared in vessels of lead, which is but slowly acted on. Or the vapour of the acid may be applied in the following manner:—The glass to be engraved is coated with etching ground on wax, and the design traced in the usual way with a pointed instrument. A small quantity of powdered fluor spar is put into a shallow basin of sheet-lead, and enough sulphuric acid added to form a thin paste with the spar. The glass is placed upon the basin with the waxed side downwards, and a gentle heat being applied beneath, the vapour of hydrofluoric acid is rapidly disengaged. In a few minutes the operation is complete: the glass is then removed, and cleaned with a very little warm oil of turpentine. The lines etched in this way are very clear and smooth. In the Great Exhibition some charming etchings on glass were exhibited from Prussian Saxony, and also from Belgium; the latter said to be by a new process.

FLUX, (from the Latin *fluo*, to flow.) Fluxes are of great use in the chemical arts. They are often required in cases of chemical action amongst metallic compounds at high temperatures. Their use is to protect the substance from the air; to dissolve impurities, which would otherwise be infusible, and to convey active agents, such as charcoal and reducing matter, into contact with the substance operated on.—See COPPER, IRON, &c.

FLY-WHEEL, see STEAM-ENGINE—WHEEL.

FOCUS, see LENS.

FOIL (from the Latin *folium*, a leaf). Metallic foils, made of thin sheet-copper, silvered and bur-

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(1) The new planes resulting from this *cleavage* of the crystal are called its *cleavage planes*. The line produced by the meeting of two planes is the *edge* of the crystal, and the meeting of any two lines or edges forms a *plane angle*. A *solid angle* is produced by the meeting of three or more plane angles. In Fig. 1046 *a*, *c*, *d* are the exterior planes of the crystal, *e*, its edges, *f*, *g*, its solid angles.

nished, and afterwards coated with transparent colours mixed with isinglass-size, are often used by jewellers to improve the brilliancy of pastes and inferior stones. [See GEMS—JEWELLERY.] Copper-foil, also, called *Nuremberg* or *German* foil, is prepared by beating thin copper plates with a polished hammer, upon a well polished anvil, until the desired reduction is obtained: the copper is then heated in the fire between two thin iron plates; next boiled in a pipkin, in a solution of equal parts tartar and salt constantly stirring until the surface becomes white the foil is then dried, and again hammered. Care must be taken not to over-heat the plates in the fire, nor must they be boiled longer than is necessary to the white appearance. The polishing is then performed upon a very smooth plate of copper, about 1 foot long, and 5 or 6 inches wide, bent into a convex surface, fastened upon a half cylinder, and fixed to a table. Some clean-washed whiting is then to be filtered through a clean linen cloth, and the copper wetted therewith: the foils are then laid on the convex surface, and polished with a polishing stone and the whitening until they are as bright as a mirror: they are then dried, and laid up secure from dust.

FOOD, PRESERVATION OF. The various organic substances furnished by the animal and vegetable kingdoms, which constitute the food of man, are, from the nature of their chemical structure, liable to change and decay: they are also irregular in their supply; hence arises the necessity of storing up the abundance of one season to meet the deficiencies of another. The art of preserving food as much as possible in its original state is therefore of great importance: it has been improved by gradual steps, depending, in great measure, as in so many other cases, on chemical discovery and the diffusion of chemical knowledge among persons engaged in the useful arts; so that, at the present time, the deprivations suffered by our forefathers may be prevented; the commonest articles of food may be enjoyed at all seasons; and even the delicious fruits of our gardens may be made to contribute to our health and refreshment at a season when the trees which produced them are covered with snow. The mariner, too, is not now necessarily confined to salt meats: he may, on the longest voyage, and in the severest clime, as easily enjoy fresh meat and vegetables as when he is in port.

The necessity for adopting means for the preservation of articles of food arises from the complicated structure of organic compounds, and their tendency to resolve themselves into simpler or inorganic compounds. Although the comprehensive history of the animal and vegetable kingdoms is written with a very brief alphabet; although the elements which enter into the composition of organic bodies are only carbon, hydrogen, and oxygen, often, but not always, nitrogen, and occasionally minute portions of sulphur and phosphorus; yet their extraordinary powers of combination are such that there appears to be no limit to the number of definite substances which they are capable of producing, each substance having a character peculiar to itself, and often a crystalline form. It is very different with the 58 other members of the list of elements; the compounds which they assist in forming are inorganic, and they are formed by the union of *pairs* of elements, or *pairs* of *binary* compounds. For example: copper and oxygen combine to form oxide of copper; potassium and oxygen form potash; sulphur and oxygen form sulphuric acid; sulphuric acid, in its turn, combines with oxide of copper, forming sulphate of copper, and with oxide of potassium, forming sulphate of potash; and even these two salts may be formed into a double compound, expressed by the formula $CuO, SO_3 + KO, SO_3$. In this way the most complicated inorganic products may be produced by repeated pairing on the part of their constituents. No such arrangement can, however, be traced in the structure of organic bodies. Sugar is composed of $C_{12} H_{11} O_{11}$; starch, $C_{12} H_{10} O_{10}$; albumen, or white of egg, has the highly complex formula, $HO, NaO, C_{144} H_{110} N_{18} S_2 O_{42} + 2 Aq$ (or bialbuminate of soda); while the salt which is necessary to give it flavour is expressed by the simple formula $NaCl$.

It is a consequence of this complicated structure, that organic compounds are unstable in their character, and liable to decomposition, or, in other words, to resolve themselves into simpler compounds. An inorganic substance, on the contrary, however complex its formula may appear, is actually built up of binary compounds, the simplest that can be formed. But in the organic substance the carbon and hydrogen have a strong tendency to form carbonic acid; the hydrogen and oxygen to form water; the hydrogen and nitrogen to form ammonia; or the hydrogen and the sulphur to form sulphuretted hydrogen, &c. In popular language, these changes are expressed by such terms as *decay* and *putrefaction*. Liebig, however, has given precision to them by limiting the term *decay* to the decomposition of moist organic matter freely exposed to the air, the oxygen of which gradually burns and destroys it without sensible elevation of temperature.[1] The term *putrefaction* is limited to changes which occur in and beneath the surface of water, the effect being a mere transposition of elements or metamorphosis of the organic body.[2] The conversion of sugar into alcohol and carbonic acid is a simple illustration of the term. The contact of oxygen is, however, first necessary to the change, which, when once begun, is continued without the aid of any other external substance, except perhaps water, or its elements. Every instance of putrefaction begins with decay; and if the decay or its cause, viz. the absorption of oxygen, be prevented, no putrefaction occurs. In short, if the access of oxygen be

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(1) Hence the term employed by Liebig and his followers, *eremacausis*, or *slow-burning*.

(2) "The colourless fresh cut surfaces of a potato, of a turnip, or of an apple, when exposed to the air, soon become brown. In all such substances the presence of a certain quantity of water, by which the molecules are enabled to move freely on one another, is a condition necessary to the production, by temporary contact with air, of a change in form and composition, a resolving of the original body into new products, which continues uninterrupted till no part of the original compound is left. This process has been distinguished by the name of *putrefaction*."—*Liebig*.

prevented, there is no decay; if the access of water be prevented, there is no putrefaction. The exclusion of air and moisture forms the basis of some of the best methods of preserving food.

There are certain substances named *Antiseptics*, (from ἀντὶ, against, and σήπομαι, to putrefy,) from their property (exerted, however, very unequally) of preventing the putrefaction of organic substances. Thus, alcohol and common salt in certain proportions, check all putrefaction and all the processes of fermentation by depriving the putrefying body of water. Nitre, vinegar, spices, and sugar are also antiseptics. The antiseptic effect of a very low temperature is caused by the solidification of the water and other juices, which, in their usual fluid state, allow the molecules to move freely on one another.

We will first notice the various methods of preserving animal food; these are:—1. by drying; 2. by cold; 3. by salting and by sugar; 4. by smoking; 5. by vinegar; 6. by parboiling and excluding air; 7. by potting; 8. by alcohol.

1. A familiar example of the first method is afforded in common glue, which in its hard and dry state may be kept for any length of time. So also may white of egg, if prepared in the manner directed for fining coffee. [See COFFEE, p. 409.] These two substances, *gelatine* and *albumen*, are two of the constituents of flesh; *fibrin* or *fleshy fibre*, which is the third, dries equally well, and is not liable to putrefaction in that state. Gelatine, after being dried, may be softened by the action of hot water. Albumem *coagulated* by heat cannot be softened again by water; but if dried at about 140° without being coagulated, it may be dissolved in cold water, retaining all its valuable properties. Hence, in preserving meat by drying, too high a temperature must be carefully avoided, or the albumen will become coagulated, and the meat be made insoluble.

The dried flesh of the bison, of the buffalo, and of the deer forms *pemmican*, the preparation of which is thus described in Captain Back's Journal:—

"While meat remains in a thick piece, it is impossible to get the middle dried before putrefaction commences; but if the meat be cut into slices, its desiccation may be easily effected. The fleshy parts of the hind quarters are cut into very thin slices, dried in the sun, or before the fire, and pounded. Two parts of the pounded meat are then mixed with one of melted fat, and packed into a bag formed of the hide of the animal. A bag weighing 90 lbs. is called a *taureau* by the Canadian voyageurs; and in fact, only one bag of pemmican is generally made from each bison cow. Two pounds of this kind of food are sufficient for the daily support of a labouring man; though, when the voyageurs first commence upon pemmican, they each consume 3 lbs. or more. In the spring, they generally boil the young shoots of the *Epilobium angustifolium* with it, and some Scotchmen in the service of the Hudson's Bay Company, add flour or oatmeal, thus rendering it more palatable. The best pemmican is made of finely pounded meat mixed with marrow, and further improved by the addition of dried berries or currants. If kept from the air, it may be preserved sound for several years, and being very portable, it might be used with great advantage in provisioning troops that have to make forced marches. It may be eaten raw, or mixed with a little water and boiled; and although not much relished by those who taste it for the first time, the voyageur, with the single addition of the luxury of tea, requires nothing else for breakfast, dinner and supper."

In the West Indies, and in South America, jerked beef is prepared by cutting the meat into slices, dipping them into sea-water or brine, and then drying them in the sun. The flesh of wild cattle is thus preserved at Buenos Ayres. Sometimes this dried meat is pounded in a mortar, into a uniform paste, which is pressed into jars, and if intended to supply the wants of the traveller, it is beaten up with maize meal and packed closely in leather bags. It is eaten in this state without further cooking. Drying meat in the air is said, however, to injure its flavour, and to dissipate a great portion of the nutritious juices.

Some kinds of fish are preserved by slitting them down the middle, and drying them in the air to evaporate the moisture. Small cod, haddock, and stock fish, prepared in this way, will, if kept dry, remain good for a great length of time.

Portable soup is prepared by processes similar to those used in the manufacture of glue. [See GLUE.] The gelatine of meat is dissolved by boiling water, and the water being evaporated, the gelatine is left in a solid state. Any fresh lean meat, with the fat cut away, will answer the purpose. Bones are also used for the purpose, [see BONE,] the gelatine being extracted by means of a digester. [See DIGESTER.] In the French manufacture of *gelatine brut fin*, 100 lbs. of bones yield about 25 of gelatine, which is dried, cut up into dice, and used for making soup.

2. The effect of cold in the preservation of animal substances received a remarkable illustration in the discovery made by Pallas, in the year 1779, on the shores of the Frozen Ocean, near the mouth of the river Lena, of an animal of immense size, imbedded in ice, which, as it melted gradually, exposed it to the air and furnished food for the hungry wolves and other animals of those regions. It was the opinion of Cuvier, that this animal differed from every known species of elephant, and was antediluvian, preserved from the remote period of the deluge in the mass of ice which enveloped it. Some of the hair of this animal may be seen in the museum of the Royal College of Surgeons, in Lincoln's Inn Fields.

In Russia, Canada, Hudson's Bay, and other countries where the frost is sufficiently steady, meat preserved in this way is a common article of commerce. Travellers speak with admiration of the frozen markets of Russia, supplied as they are from distant places with provisions solidified by the cold. Thus, in the market at Petersburg, Mr. Kohl noticed partridges from Saratoff, swans from Finland, heath-cocks and grouse from Livonia and Esthuria, while the wide Steppes furnished the trapp-geese which flutter over then across plains, where the Cossack hunts them on horseback, and kills them with his formidable whip. All these birds, as soon as the life-blood has flown, are apparently converted into stone by the frost, and, packed in huge chests, are sent for sale to the capital. So rapid are the effects of frost in that country, that the snow-white hares which are brought in sledge-loads to the market, are usually frozen in the attitude of flight, with their ears pointed and their legs stretched out, just as they were at the moment of death. Another curious sight in these markets is a frozen rein-deer, its knees doubled under its body, its hairy snout stretched forth upon the ground, and its antlers rising majestically in the air; or a mighty elk, disappearing piece by piece, as the action of the saw and the axe separates it for distribution among the several customers.

When provisions have been frozen, great care is required in thawing them; for if this be done suddenly, putrefaction soon sets in, and although cooked immediately, they are hard and deficient in flavour. They must be thawed by immersion in cold water.

The London markets are supplied with salmon packed in ice from many of the northern rivers that flow to the eastern coasts of Britain. Every salmon fishery is now provided with an ice-house, and a stock of ice collected during the winter. The salmon is packed in large oblong wooden boxes, with pounded ice between, and the fish is received in London as fresh as when it was taken out of the water. It is not, however, frozen. Most fishmongers are furnished with ice-houses or cellars for the preservation of their fish in tubs of ice; and we do not see why butchers should not be provided with larders cooled by the same means. In many parts of the United States every housekeeper has a small ice-safe, in which, through the warm season, all kinds of perishable provisions are kept. Public ice-houses are also maintained by the butchers, so that under the burning climate of South Carolina there is less loss in the way of butcher's meat, fish, game, &c., than in the comparatively temperate summer of our own metropolis. The meat is sent to the ice-house near the market, every evening, and is cooled down to near the freezing point during the night; when exposed on the stalls next day it retains its low temperature for a long time. Such a plan, adopted in London, would prevent the immense waste of meat during every summer, which is said to amount to at least 2,000 tons in London alone. It is true that when meat has been once frozen its flavour is injured, but the reduction of meat to 32° or thereabouts, and the solidification of its juices, are very different things: and it would be easy to regulate the temperature within a range of several degrees. [See ICE.]

3. Various kinds of salt are used in the preservation of food; these will be described under SODIUM, *Chloride of*. Saltpetre and sal-prunella (which is saltpetre deprived of its water of crystallization by heat) are also used for the purpose. The action of these alkaline salts upon animal substances is, as already noticed, to abstract the water in the juices of the meat, and being dissolved therein, the salts enter the pores of the animal substance; the albumen of the meat, which is more liable to putrefaction than the gelatine and fibrine, is thus rendered less so. There are two methods of salting, *dry-salting* and *pickling*. In dry-salting, the meat is packed in dry salt, or in some cases the surface is rubbed all over with salt. In pickling, the meat is kept immersed in a solution (sometimes saturated) of common salt dissolved in water. This method does not render the meat so salt as dry rubbing, and is probably less injurious to its nutritious qualities, but it will not keep the meat so well. Bacon is *cured* by salting and drying, for which latter purpose it is often hung up in the wide chimneys of farm-house kitchens; cod is also salted and dried for the large demand of the Peninsula; in England, it is used in a *green* state; that is, instead of being split quite open, it is only opened down to the navel, then salted, and laid in brine or strong pickle, and put into casks without drying. Haddock, cod, or ling, are cured by splitting the fish and removing the backbone; they are then salted for two or three days, with equal parts of salt and sugar, or with salt alone; they are next stretched on sticks, and laid on the beach to dry in the sun, or they are arranged on stages, or hung up in an enclosed space warmed by a stove. Herrings are salted or pickled, and smoked.

Sugar, like salt, takes away the water from animal substances, and thus prevents putrefaction. By immersing meat in molasses, it has been preserved fresh for months. Fish is sometimes preserved by cutting it open, rubbing in sugar, and leaving it for a few days; it is then dried in the air, taking care to turn it frequently. For a salmon of six pounds weight, a table-spoonful of brown sugar is sufficient; but if hardness be required, a teaspoonful of saltpetre is to be added.

4. The efficacy of *smoking*, or *smoke-drying*, arises not only from the heat of the smoke, but from certain chemical products disengaged during the combustion of the wood fuel used for the purpose. Pyroligneous acid vapour and kreosote are both produced, and the latter substance possesses the remarkable property of coagulating albumen. Hence, those chimneys only are fit for the purpose where the fire below is wood or peat, not coal. The kind of wood burnt is also of importance, the smoke from beech and oak being preferable to that from fir or larch. Smoke from the twigs of juniper, rosemary, peppermint, &c. impart to the meat a portion of their aromatic flavour. Westphalia hams owe some of their excellence to being smoked by juniper. Slow smoking is preferable to rapid, as it penetrates completely into the interior of the meat. In some parts of the country, the drying and smoking of hams is a separate trade, a charge of 4*d*. or 6*d*. per ham, and 1*s*. for a flitch, being made. In such cases, a smoking-house or hut is erected, about 12 feet square, and the walls 7 feet high, with a hole in the roof; joists are laid across inside, to hang the flitches on, and the floor is covered 5 or 6 inches deep with saw-dust, which being kindled, produces much smoke and little flame.

5. Vinegar and some other acids preserve both animal and vegetable substances by coagulating their albumen, which, as already stated, is peculiarly liable to putrefactive fermentation.

6. In the year 1810, M. Appert received a reward of 12,000 francs from the French Government for his method of parboiling provisions, and enclosing them in earthenware vessels in such a manner as to exclude the air.[1] Many vegetables, fruits, &c., can be kept fresh for a great length of time, by shutting them up closely in a vessel, having previously filled up the interstices with sand or other loose substance that will exclude nearly all the air. Fresh walnuts may be preserved in this way in a jar, packed with sand and closely covered over; grapes packed in sawdust are imported into England from the Peninsula. Meat cannot be preserved in this way, but by exposing it to the heat of boiling water, the albumen, in which putrefaction first commences, coagulates; and as coagulated albumen is somewhat slow in decomposing, we thus have a reason for the common observation that cooked meat will keep longer than raw. It will not, however, keep many days, unless the air be perfectly excluded, not only from the external, but from the internal parts. The air in the interior may be expelled by boiling, and the exterior air may be kept away by enclosing the substance in an air-tight vessel. If these conditions be carefully observed, food may be preserved for any length of time. Appert's method consists in applying heat to the substances to be preserved, so as to coagulate their fermentable juices, and then to place them in such a situation as to deprive them of contact with air. The vessel in which the meat is prepared, is plunged for some time into boiling water before it is finally sealed, in order to drive out the last portions of the air; for if a small portion of oxygen gas were present, this would be sufficient to commence the process of fermentation, and when once begun it would be continued.

Messrs. Donkin & Co. took out a patent in this country for M. Appert's process, which, as improved by them, may be described as follows:—

The meat to be preserved is first parboiled, or somewhat more, and freed from the bones. It is then put, together with vegetables, if required, into tin cases or canisters, which are filled quite up with a rich gravy; a tin cover with a small aperture in it is then carefully fixed on to each canister by solder, and while the vessel is perfectly full, it is placed in boiling water, or in a saline bath, heated above the boiling point of water, and kept therein until the air has been expelled as completely as possible by the steam generated within the canister. The small hole in the cover is completely closed up with a little solder while the contents are yet hot, the issue of the steam being stopped for a moment by means of a damp sponge. The canister with its ingredients is now allowed to cool, in consequence of which these contract, and the sides of the vessel are forced slightly inwards by the pressure of the atmosphere, and become a little concave. As a precautionary measure, however, the tins are placed in the testing-room, which is heated to above 100° Fahr.: should putrefaction take place in consequence of a minute portion of oxygen left in the case, and not combined with the animal or vegetable matter, the generated gases will burst the canisters; those, however, which withstand this test, will preserve the provisions for many years; for as each vessel is hermetically sealed, and all access of air prevented, it may be sent into any climate without fear of putrefaction, and the most delicate food of one country be thus eaten in its original perfection in a distant region, many months or even years after its preparation. In this manner may all kinds of alimentary substances be preserved; beef, mutton, veal, and poultry; fish and game; soups, broths, and vegetables; creams and custards. Of a quantity taken by Captain Nash to India, not one canister was spoiled; and one which he brought back contained, after two years, beef, in the highest state of perfection and preservation, and after having been carried upwards of 35,000 miles, in the warmest climates. This method has been adopted by the Commissioners for victualling the Navy, who, having examined some meat so preserved for four years, during voyages in the Mediterranean and to America, found it as sound, sweet and fresh, as if it had been boiled only the day before. Captain Basil Hall bears similar testimony. It was stated, however, by the officers in the Antarctic voyage, that they gradually got very tired of preserved meats, but not of preserved vegetables, and that there was an insipidity in them which they did not find in fresh food. There is, however, no doubt that if the articles be selected with care, and the process be properly conducted, M. Appert's method of preserving food is a valuable invention. If the contractor be careless or dishonest, the most fearful consequences might ensue to the crews of ships victualled with preserved meats. It appears from a recent examination of several thousand canisters of the preserved meat of the Navy at Portsmouth, that their contents were masses of putrefaction, consisting of meat, coagulated blood, pieces of liver, intestines, ligaments, &c., which, even in a fresh state, ought never to be used as food. It is stated that this preserved meat was supplied from Galatz, in Moldavia.

In 1842, M. Appert's method was made the subject of a further patent, granted to Mr. Bevan, whose process consisted in expelling air from the cases containing the food, by placing such cases in connexion with a vacuum chamber, or other exhausting apparatus, and also with a vessel containing gelatine or other suitable fluid material, in such a manner, that by opening the communications, the air escapes into the exhausting apparatus and the gelatine takes its place. By this method the high temperature previously used in preserving food was not required; it could, on the contrary, be cooked at very low temperatures, and in a space almost void of air. The appa-

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(1) M. Appert's method is described fully in a small volume entitled, "Le Livre de tous les Ménages, ou l'art de conserver pendant plusieurs années toutes les substances animales et végétales." A fourth edition of this book was published in 1831.

ratus used is shown in section, Fig. 1007. A is a vessel open at the top, and filled to the line i with fluid gelatine, having a pipe j, and a stop-cock e firmly attached to it. B is a sphere of metal in which a vacuum is produced by blowing steam through it by the pipe l out through k: l and k are then closed, and a jet of water at m, applied to the outside of the sphere, condenses the steam and leaves a vacuum within it. The substance to be preserved is enclosed within a cylindrical tin vessel C, the top of which is then soldered on, and two small metal pipes d and e passed into it air-tight, as far as a b; the other ends being secured to the pipes j j at h h. The case is next immersed in a water bath S, at a temperature of about 120°, and by turning the cock f, the greater portion of the air in the case C rushes into B; the article of food, animal or vegetable, in the case, being thus relieved of atmospheric pressure, the heat of 120° is sufficient to cook it, and to expel the air from it. A fowl is cooked in this way in about 15 minutes. The cock e is then opened, and the gelatine, kept fluid by the warm bath F, enters by the pipes j and e, into the case C, and drives the small portion of air left therein into the vacuum chamber B. The case C is then hermetically sealed by nipping the tubes d and e at the points g g. The case is then submitted for a few minutes to the action of boiling water, (30 minutes for a fowl,) and when cool, the process is complete.

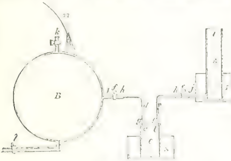

Fig. 1007.

A concentrated form of food, called *meat biscuit*, excited a considerable degree of attention in the Exhibition of 1851. It is formed by boiling down the fresh beef of Texas, and mixing into the strong beef-tea thus formed a certain proportion of the finest flour. The biscuit formed from these materials is so nutritive, that less than four ounces a-day (mixed with warm water or not, according to circumstances,) is sufficient food for a man in active service. It is very light and portable, and keeps perfectly well without change: hence it is admirably adapted to the provisioning of troops, ships, and overland expeditions. The manufacture is also of great importance to those countries in which cattle are superabundant, and are killed merely for the sake of their skins for the tanner, or their bones for the farmer, the flesh being actually thrown away. In some places, animals which we are accustomed to regard as valuable, are so numerous that they are drowned by hundreds, merely to get rid of them, neither their skins, bones, nor flesh serving as a pretext for the wholesale slaughter.

Milk has been preserved in the following manner:—Fresh milk is reduced by boiling to one-half, and beaten up with yolk of eggs, in the proportion of 8 eggs to every 10½ quarts of milk. The whole is then placed on the fire for half an hour, and skimmed frequently; it is next strained and heated in a water-bath for two hours. It is stated that this milk will keep good for two years, and if churned, would afford good butter. Cream may be preserved by boiling five measures down to four; then, after cooling and skimming, it is put into a bottle, corked down, luted, and kept in the boiling heat of a water bath for half an hour. This, it is said, will keep two years.

A much better method of preserving milk is that first pointed out by M. Duchoff, the Russian chemist, namely, to solidify it by driving off the aqueous portion by a gentle heat. Specimens of consolidated milk were shown in the Exhibition of 1851; and it was stated, that after being dissolved in boiling water, and reproduced in the form of milk, the solution will keep pure for four or five days. As milk contains 873 parts water in every 1,000, it follows that 1,000 parts of milk will yield by evaporation only 127 parts.

7. *Potting* is only another contrivance for excluding animal substances from contact with air. Lean meat should be selected, cooked, and then reduced to a pulp by being beaten in a mortar, salt and spices being incorporated. The pulp is then rammed into jars, and preserved from the air by a thick coating of melted butter or lard, poured over it.

In the preservation of fruits and vegetables some are dried, as in the case of nuts, raisins, sweet herbs, &c.; others are preserved by sugar, such as many of the fruits, whose delicate juices would be dissipated in the process of drying. Some are preserved in vinegar, as in the case of pickles; a few by salting, as French beans; and others are preserved in spirits.

Appert's method applies to vegetables and fruits of all kinds; they need not, however, be parboiled. The dry and fresh-gathered fruits are put into strong, wide-mouthed glass bottles, carefully corked, and luted with a cement of lime and soft cheese, and bound down with wire. The bottles are then enclosed separately in canvass bags, and put into a kettle of water, which is gradually heated until it boils; the bottles are kept in this condition until the fruits are boiled in their own juice. The whole is then left to cool; after which the bottles are examined separately, and put away for store.

Many kinds of vegetables may be preserved by being spread out on the floor of a kiln, and dried by a gentle heat: the thicker kinds of roots, such as carrots, turnips, potatoes, &c., are to be sliced, and thoroughly well dried; after which, they must be packed up in paper or very dry boxes, and put into casks.[1]

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(1) The flour and biscuit which are taken out to sea in the British navy are packed in casks of wrought iron. These were formerly painted, to prevent rust, and also to make them water-tight, but the paint was found to give a bad taste to the flour, &c.

A method of preserving vegetables by drying and pressure, recently invented by M. Masson, was brought into prominent notice at the Exhibition of 1851. Cabbage, sliced turnips, apples, or whatever vegetable be selected, is dried in an oven at a certain temperature, so as to drive off from 7 to 8 per cent. of water: the drying must not be conducted too slowly nor too rapidly, but at a medium rate. After the drying, the vegetables are packed into a very small compass by the intense pressure of a hydraulic press; then squared and trimmed with a knife, packed up in tinfoil, and lastly, stored in boxes. A few years ago, we examined some red cabbage preserved in this way, which had been exposed in the Exhibition of 1851 all the time it was open, and had been slowly absorbing moisture, and yet it appeared to be perfectly good. By this method, from 15,000 to 18,000 rations, of ¼ lb. each, can be stowed into a cubic yard. We also saw some dried plantains from Mexico, (a vegetable of very considerable nutritious value,) which had been lying in a warehouse at Woolwich ever since the year 1835, and had undergone no change. It was stated that the method of preparing them is cheap and easy, and that the dried plant can be sent in any quantities to Europe, at 3*d.* per lb., with a considerable profit to the importer.

Some kinds of vegetables, such as French beans, artichokes, olives, samphire, and barberries, are preserved by salt, a strong brine being made by the addition of four pounds of salt to a gallon of water; the vegetables are put into this, and quite covered with it. In Holland and Germany, kidney-beans are sliced by a machine something like a turnip-cutter, and put into a cask in layers with salt between; a weight is then put on, and pressure is kept up until a slight fermentation takes place; the salt liquor is then poured off; the cask is covered up, and put into the cellar as store. Before being cooked, the beans are steeped in fresh water.

Sauer Kraut is prepared somewhat in the same manner. The following recipe for making it is given by Parmentier:—

The heads of white winter-cabbages, after removing the outer leaves, are to be cut into fine shreds, and spread out upon a cloth in the shade. A cask which has had vinegar in it is to be selected, or if that cannot be had, the inside should be rubbed over with vinegar, or sauer-kraut liquor. A layer of salt is to be put in the bottom of the cask, caraway-seeds are to be mixed with shreds of cabbage, and they are to be packed in the cask to the depth of four or six inches; and layers of this kind, with salt between each layer, are added till the cask is full, stamping them down with a wooden stamper as they are put in, to half their original bulk; some mix a little pepper and salad oil with the salt. Some salt is to be put on the top, and some of the outside leaves of the cabbages. About 2lbs. of salt suffice for 20 middle-sized cabbages. The head of the barrel is to be placed upon the cabbage-leaves, and must be loaded with heavy stones. A common method is for a man, with clean wooden shoes on, to tread the cabbage down in the cask. Fermentation will take place, and some juice will be given out, which is green, muddy, and fœtid: this rises to the surface, and is to be replaced with fresh brine. When the fermentation is over, the casks are closed up. Cabbages are preferred, but any other vegetables may be treated in the same manner.

When vegetables are preserved in vinegar, they form *pickles*. When sugar is the preserving medium, they are variously named according to the mode of preparation. Fruits, flowers, herbs, roots, and juices, boiled with sugar or syrup, and employed in pharmacy, as well as for sweetmeats, are called *confections* (Latin, *conficere*, to make up). *Liquid confects* consist of fruits, either whole or in pieces, preserved by immersion in fluid transparent syrup: apricots, green citrons, and some foreign fruits, are treated in this way. *Dry confects* are prepared by boiling in syrup those parts of vegetables adapted to this method, such as citron and orange-peel, &c.; they are then taken out and dried in an oven. *Marmalades, jams,* and *pastes* are soft compounds made of the pulp of fruits, or other vegetable substances, beaten up with sugar or honey: oranges, apricots, pears, &c., are treated in this way. *Jellies* are the juices of fruits,—currants, gooseberries, apples, &c.—boiled with sugar to such a consistence as, on cooling, to form a trembling jelly. *Conserves* are dry confects, made by beating up flowers, fruits, &c. with sugar not dissolved. *Candies* are fruits candied over with sugar after having been boiled in the syrup.

The best syrup for preserving fruits is made by dissolving two parts of double-refined sugar in one part of water, boiling a little, skimming, and filtering through a cloth. This gives a good smooth syrup, which does not readily ferment nor crystallize.

The specimens of preserved food in the Exhibition of 1851 were exceedingly numerous: they included animal and vegetable productions, fruits, &c. One interesting specimen was a canister containing boiled mutton, prepared by the exhibitor, Mr. Gamble, for the Arctic Expedition in 1824. A large number of these canisters were landed from H. M. S. *Fury*, on the beach where the ship was wrecked in Prince Regent's Inlet, and were found by Captain Sir John Ross in August, 1833, in a state of perfect preservation, although annually exposed to a temperature of 92° below, and 80° above zero. Had it not been for the large store of provisions left by Parry near the spot where the *Fury* was wrecked, Ross's expedition must have perished. [See APPENDIX.]

FORCE, see MECHANICS.

FORGE—FORGING. Some of the varied manipulations of the forge, concerned in the production of small articles in iron and steel, are described in the article CUTLERY. In the present article a few details will be given respecting the forging of large articles; but we must also refer to IRON and STEEL for further information; inasmuch as the process of forging may be said to commence as soon as the *ball* of iron is

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and they are now coated outside with a waterproof composition of caoutchouc, black resin, and Venice turpentine.

taken out of the puddling furnace, and receives its first blow from the helve, in the process of converting it into a bloom.

In addition to the ordinary business of a large iron-work, which consists in the production of bar, plate, and hoop-iron, the hammer-men are also employed in preparing masses of metal or *uses*, several of which are *used* or welded together in the construction of a large work. For example, in the forging of a square shaft, as many as from ten to twenty square pieces of iron may be bound together, and put into a powerful air-furnace, the ends of the bundle being welded together by a hammer weighing five tons; after which the weld is extended throughout the length. The paddle shafts of the largest steam-ships are formed by successive additions at the end of a mass of iron: for instance, a slab or *use* is welded on one side near the end, and both are hammered or *drawn* down to the common thickness, so that the additional matter is thrown into the length: another slab or *use* is added to the adjoining side of the as yet square shaft, and also drawn down into the length, and so on, until the proper size is attained. In the paddle shafts built by Messrs. Maudslays for the *Great Western* steam-ship, consisting of three pieces connected by drag-links, the middle length was 12 feet long; the two outer, or the paddle-shafts, each 22 feet long; the largest, or central diameter, was 18 inches; they tapered off to 12 inches at the external parts, and the bearings were 16 and 15 inches diameter. The weight of the three pieces was nearly 20 tons, and their value before they left the forge was upwards of 1,000*l*.

In the forging of such heavy works, Nasmyth's steam hammer is now principally used, and the ponderous masses of red-hot metal are managed with wonderful facility. "First, the *work* has a long iron rod attached to it in the line of its axis, to serve as a *porter* or guide-rod. The mass is suspended under a traversing crane, at that point where it is nearly equipoised, and the crane not only serves to swing it round from the fire to the hammer, but the traverse motion also moves the work endways upon the anvil, and small changes of elevation are sometimes effected by a screw adjustment in the suspending chain. The circular form is obtained by shifting the work round upon its axis by means of a cross lever fixed upon the porter, and moved by one or two men, so as to expose each part of the circumference to the action of the helve: this is readily done, as the crane terminates in a pulley, around which an endless band of chain is placed, and the work lies within the chain, which shifts round when the work is turned upon the anvil. The precision of the forgings produced by these means is very surprising."[1]

Smaller works are also forged in a somewhat similar manner. Several bars are often piled together and *faggoted*; that is, a round bar in the centre is surrounded by a group of bars of angular section, called *mitre-iron*, and are wedged together in a hoop. Or *scrap-iron* is used; that is, the odd scraps and refuse of a variety of works are enveloped in an old piece of sheet-iron, and held together by a hoop; the mass is raised to the welding heat in a blast or air furnace, and the whole is consolidated and drawn down under the tilt hammer; one long bar, to serve as a porter, being welded on by the first blow. [See GUN.]

In heavy works of somewhat complex form, such as anchors, hand forging is found most convenient. As this is very laborious work, two gangs, of six or twelve men each, are employed, who relieve each other at short intervals. Each man is armed with a heavy sledge-hammer, and the hammers are all swung round and made to fall upon any one particular spot with remarkable regularity, the blows being directed by a foreman with a long wooden wand. Square shanks of anchors are also partly forged under a vertical hammer, called a *monkey*, consisting of a long iron bar running loosely through an aperture several feet above the anvil, and terminating at the foot in an iron ram. This hammer is elevated by a chain attached to the rod and also to a drum above, which is put in gear with the engine, and suddenly released by a simple contrivance when the hammer has reached the height of from 2 to 5 feet. The ram is made to fall upon any point indicated by the foreman's wand, as it has a horizontal range of about 20 inches from the central position, and is guided by two slight eye-rods hooked to the ram, and placed at right angles: these eyes are held by two men who watch the motion of the foreman's wand.

Shovels, spades, mattocks, cleavers, and other implements and tools are partly forged under the tilt-hammer. We shall have occasion to notice the subject of *tilting* in the article STEEL. [See IRON and STEEL.]

Works of large size are heated in air furnaces, as already noticed. When they are short and complex in figure, the open fire or smith's hearth is used. The largest kind of smith's hearth is a trough or pit of brick-work, about 6 feet square, elevated about 6 inches from the ground: one side of the hearth is extended into a vertical wall leading to the chimney, the lower end of which terminates in a hood of stout plate-iron for collecting the smoke. The back wall of the forge is fitted with a large cast iron plate or *back*, in the centre of which is a thick projecting nozzle of iron, perforated, and forming what is called a *tuyere*, for admitting the blast which urges the fire. The blast may be supplied from bellows, by a revolving fan, or by one of the methods described in BELLOWS AND BLOWING MACHINES.[2] The cast iron back is liable to crack from the heat: to prevent this, it is made hollow, and a stream of water from a small cistern allowed to circulate through it; or air in its passage from the blowing apparatus is passed through it, and thus a *hot blast* is formed. The forge used in forging small works is described under CUTLERY.

FORK, see CUTLERY.

FORMIC ACID. In our notice of ACETIC ACID it was shown that alcohol, by oxidation, under the influence of finely-divided platinum, produces acetic acid. When wood spirit $(C_2H_3O + HO)$ is exposed under similar circumstances, a peculiar acid is produced, by the substitution of two equivalents of oxygen for two of hydrogen. This acid is named *formic* (C_2HO_3), from the circumstance of its having been first found in the bodies of ants. The hydrated acid ($C_2HO_3 + HO$) is a clear colourless liquid which fumes slightly in the air; it has a very penetrating odour; it boils at about 212°: when cooled below 32° it crystallizes in large brilliant plates. Its sp. gr. is 1·227: it mixes with water in all proportions; the vapour is inflammable, burning with a blue flame. There is a second hydrate containing two equivalents of water: its specific gravity is 1·11, and it boils at 225°. In its concentrated form it is very corrosive. A more dilute acid may be prepared by heating starch sugar and other organic substances with oxidizing agents. Formic acid may also be obtained by distilling ants with water, or simply by macerating them in the cold liquid. The salts formed by this acid with bases are termed *formates*. The chemical relations of formic acid will be further noticed under Wood, *distillation of*, p. 1025.

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[1] Holtzapffel: Mechanical Manipulation, vol. i.

(2) A portable forge is described in this article.

FOUNDATION. See Bridge—Bricklaying.

FOUNDING. See Casting.

FOUNTAIN. See Artesian Wells.

FRAMING. See Carpentry—Floors and Partitions.

FRANKFORT BLACK. See Carbon, p. 316.

FRANKINCENSE, common, is the spontaneous exudation of *Abies communis*: it concretes into yellow drops or tears. It is a vegetable hydrocarbon. For the genuine *thus*, or frankincense of the ancients, see Olibanum.

FREESTONE, a term applied to such of the sandstones used for building as work *freely* under the tools. See Stone, p. 747.

FREEZING. See Heat.

FREEZING POINT. See Thermometer.

FRENCH POLISH consists of a resin or a gum-resin dissolved in spirit, and used for polishing flat surfaces. For this purpose it is made more fluid than the hardwood lacker, used in polishing turned surfaces, in order that it may spread easily and dry less rapidly; because the friction being derived entirely from the motion of the hand, more time is required than in polishing turned works.

The recipes for making French polish are innumerable. Indeed, it is seldom prepared in the same manner by two different makers. Some prefer it very thin, others tolerably thick; some, of one colour; some, of another; while others make it colourless or nearly so. The simplest method is to dissolve 1½ lb. of shell-lac in 1 gallon of spirits of wine without heat. Copal, sandarac, mastic, and gum arabic are sometimes used in various proportions, according to the fancy of the preparer. Some recommend 12 ounces of shell-lac, 6 ounces of gum arabic, and 3 ounces of copal, to 1 gallon of spirits of wine. A dark-coloured polish is prepared with 1lb. of shell-lac, ½lb. of benzoin, and 1 gallon of spirits; or 1½lb. shell-lac, 4 ounces of guaiacum, and 1 gallon of spirits. Dragon's blood may also be used to give the required tint.

The hardest and most durable polish is made with shell-lac and spirits without any other ingredients. It is usual to make the varnish thicker than is required for use, and to thin it down with spirit when being used. A tough polish is said to be produced from 1½lb. of shell-lac, 4 oz. of seed-lac, 4 oz. of sandarac, and 2 oz. of mastic to the gallon of spirit; or 2lbs. of shell-lac and 4 oz. of thus to the gallon. A light-coloured varnish may be made with bleached or white lac; but this darkens by exposure to light.

The rubbers used for French polishing are sometimes made of small balls of wadding, such as is used for ladies' dresses, covered with linen rag. The rubber, which is about the size of a walnut, is placed on the open mouth of the bottle, which is then turned up, and the varnish thus collected is covered with a second rag, and moistened with one or two drops of linseed oil: the varnish gradually exudes according to the degree of pressure given to the ball, which is thrown away after being used 4 or 5 minutes, as it hardens from the accumulation of the varnish, and then scratches instead of polishing the work. This wasteful method is often superseded by the use of sponge, applied in the same manner as the wadding: this forms a durable rubber, but requires to be softened every time it is used. Small cloth or list rubbers are also used for laying on the first coat: the list should be torn off the cloth, which gives a softer edge than if cut; then wound up spirally to the diameter of 2 to 4 inches, and tied round tightly with string: these rubbers are covered with a cloth so as to be easily renewed; or the lower face of the rubber itself may be saturated with lacker, so as to soften that which may remain in the rubber from previous use, and the excess is squeezed out before commencing the polishing.

Mr. Holtzapffel remarks,[1] that the choice of rubber is not very material, provided it be moderately soft and contain a sufficient quantity of polish to allow of its being gradually supplied to the work as the polishing progresses; but the rubber must always be kept covered with a piece of soft rag moistened with oil, and renewed when it becomes so far clogged as to prevent the polish passing freely through it. Before the polishing, the work must be well smoothed with fine glass paper, and the dust wiped away: the polishing is then commenced with free, continuous, uniform circular strokes with light pressure, and gradually extending over the whole surface, taking care that every portion receives an equal but moderate quantity of varnish, which is regulated by the degree of pressure on the rubber, and also by squeezing it between the fingers. The rubber must never be allowed to remain stationary on the work, or be lifted directly from it; when removed it should be slid off at the sides or ends of the work, or lifted off with a sweeping stroke so as to break contact gradually. The polishing is continued until the grain of the wood appears to be thoroughly filled up, and the surface exhibits a uniform appearance. It is then allowed to stand for an hour

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(1) Mechanical Manipulation, vol. iii

or two weeks' time, after which it is smoothed again with very fine glass-paper. The polishing is then repeated; and, if necessary, again smoothed, and the polishing continued until the whole surface presents a smooth, uniform and tolerably bright appearance. Cloudy marks produced by the oil of the rubber will, however, still appear; these are removed with a clean rubber, covered with a clean soft linen rag and touched with a few drops of spirits of wine: with this the work must be rubbed with very light strokes, applied first with a circular motion, and when the surface is nearly dry, straight strokes are taken lengthways of the grain of the wood, and traversed entirely off the ends of the work: when the rubber and the work are quite dry, the polishing will be completed for that time. In the course of a few days, the polish having been partly absorbed by the wood, the surface should be again smoothed with very fine or nearly worn-out glass-paper, and the polishing repeated. The final body of polish must be as thin as possible, or the varnish will not be smooth and durable. See VARNISHES.

FRESCO PAINTING. An ancient and still esteemed mode of decorating buildings with paintings of a permanent kind, executed on the *fresco*, or *fresh* plaster of the wall. The nature of the work requires great rapidity and skill in the painter; all that is begun in the morning must be completed in the evening while the plaster is wet, as any subsequent retouching destroys the purity of the work. The general practice of this art relates to the following particulars:—1, the cartoon; 2, the preparation of the wall; 3, the painting; 4, the colours and implements used. Since the artist is unable, without injury to the general effect, to retouch a fresco painting, it is the more important that he should prepare beforehand a finished coloured sketch of the subject he intends to represent, and also a full-sized chalk drawing of the same. For this latter purpose he prepares a cartoon, by straining strong cloth on a frame, and then glueing layers of paper to the surface, which must be kept smooth and even, and finally prepared to receive the drawing by a preparation of size and alum. The drawing is made with charcoal, and when finished and fixed, an outline is traced from it on oiled paper. This is the working outline, a portion of which, corresponding with the quantity of fresco painting which can be executed at one time, is nailed to the wet wall, where the forms on the oiled paper are gone over with a sharp point so as to make a distinct indentation on the soft plaster beneath. Another way of producing the outline on the wall is, to place the tracing paper first, at the back of the cartoon, and prick the figures through, then to lay the pricked paper on the wall, and dust a black or red powder on it from a muslin bag. This produces a dotted outline on the plaster, and leaves the surface without indentation; but it injures the cartoon, and also gives less decided lines to work by. That both these methods were practised by the most celebrated painters, is evident from the pricked outline being visible in some of the works of Caracci and Raphael, and by the indented outline produced by tracing being likewise seen in some of the best Italian frescoes.

The preparation of the wall for fresco-painting is a matter of great importance. The chief thing to be dreaded is damp; therefore all old mortar is removed, and the solid wall laid bare, preparatory to a new coat of approved materials. This consists, in the first place, of lime and river sand, laid on roughly, and left to become perfectly dry and hard, before the smoother layers are added. The lime has to undergo careful preparation and seasoning before it is fit to be thus employed. The method of seasoning it, adopted at Munich, is as follows:—A pit is filled with clean burnt limestone, which is slaked, and then stirred continually till it is reduced to an impalpable consistence. The surface having settled to a level, clean river-sand is spread over it to the depth of a foot or more, so as to exclude the air, and, lastly, the whole is covered with earth. Thus it remains for two or three years, before it is used either for painting (lime being the white pigment) or for coating walls.

The final preparation of the wall consists in wetting it till the first rough coat will absorb no more water, then laying on a thin coat of plaster, and when this begins to set, adding a finer coat, containing more lime and less sand. This is done and the work smoothed with a wooden trowel; but only so much space is finished in this way, at one time, as can be painted on before it gets dry.

The wall thus prepared, the outline has to be obtained from the cartoon in one of the two ways already described. The colouring can be commenced as soon as the plaster is in that state in which it is damp enough to receive the impression of the finger, and not wet enough for the colours to run: if the drying goes on too rapidly, the surface of the plaster must be sprinkled from time to time with water. The colours, ground fine in water, are abundantly supplied to the artist in pots or basins, and several palettes are at hand to work from. Tiles, or other absorbent materials, are used to try the colours on, and to give the artist an idea of their effect when dried into the plaster. When the artist concludes his work for the day, he cuts away any portion of the prepared plaster which he has not used, taking care that the division is made in the folds of drapery, or in some other part of the painting where it will be unobserved: on commencing the next day's work he takes care to wet the edges of the finished part, and make them amalgamate as nicely as possible with the new plaster. The drying of the plaster is sometimes arrested by foreign artists by keeping wet linen stretched over the surface of the picture, and pressed to it by a cushion of waxed cloth: this enables them to finish in the morning what they were unable to complete overnight. Defects in a painting are sometimes remedied by cutting out a portion of old plaster, and painting that portion over again on new plaster. There are also various devices for heightening the effect of finished frescoes, but these are all objectionable, as impairing the durability of the work.

The colours used in this art consist chiefly of earths and a few metallic oxides variously prepared. Animal or vegetable substances cannot be employed, because the lime would destroy them. Brushes of hogs' hair, and smaller pencils of otters' hair, are found to resist the action of the lime. Distilled water should be employed in all the operations connected with fresco-painting.

A new mode of fresco-painting, the invention of which is ascribed to a well-known German chemist, Obergrath von Fuchs, consists in the use of a solution of silex, instead of lime, and in the employment of a chemically prepared ground, which becomes exceedingly hard, and can be worked on repeatedly without detriment to the general effect.

Many valuable ancient paintings in fresco have been saved from destruction by ingenious modes of transferring them from badly constructed walls to canvas. An attempt of this kind was made at Brescia, in 1829, by Mr. Ludwig Gruner, and met with perfect success. The frescoes existed on the old walls of the convent of St. Eufemia. These were first thoroughly cleaned: a strong glue was then passed over the surface, to which a sheet of fine calico was affixed: other layers of glue and of calico were then added, and the whole so amalgamated by heat as to become of one substance with the plaster of the wall. The whole was then torn away, leaving the wall white, and the fresco adhering to the glue. To detach it, a still stronger glue, and one that resisted moisture, was applied to the back, and secured to the canvas. The subsequent application of tepid water gradually caused the calico and glue to loosen their hold, and leave the fresco in its new position.

Much interesting information on the subject of fresco painting may be gathered from the Appendices to the Reports of the Commissioners on the Fine Arts, 1842, 1843. [See Appendix.]

FRICTION is the resistance which opposes itself, in a greater or less degree, under all circumstances, to the motion of a body when in contact with another body. This resistance occurs, though to a less extent, when the surfaces are as well smoothed and polished as possible; and as it is not necessarily attended (at all events perceptibly) with any abrasion of those surfaces, it may probably have its origin in some modification of molecular adhesion.

The effects of this action have been studied under two conditions. The *friction of quiescence* is that which forms the resistance to the first motion of a body previously at rest on a surface. The *friction of motion* presents itself after movement has commenced, and acts continually to retard or check that movement.

The results of numerous experiments have established the following general laws of friction :—

1. That when no unguent or lubricating substance is interposed between the rubbing surfaces, the amount of friction, or the ratio of the resistance to sliding motion to that of the insistent pressure, is independent of the extent of the surfaces in contact and of the velocity of motion, and that it is determined solely by the nature and material of those surfaces and the force with which they are pressed together.

2. That when unguents or lubricating substances are used, the friction depends on the nature of the unguent, on its greater or less abundance, and on the proportion of insistent pressure to the extent of bearing surface.

These laws apply to both conditions of friction, but with more accuracy to the friction of motion than to the friction of quiescence.

The ratio which the resistance to sliding motion bears to the force pressing the surfaces together is called the *coefficient of friction*. Its value has been determined experimentally for almost all materials likely to be used as rubbing surfaces in practical works, and for all pressures varying between the lightest and that which produces abrasion of the substances in contact. The coefficient of the friction of quiescence is generally greater than that of the friction of motion, but as the smallest jar or shock is sufficient, during the application of a force tending to produce motion, to change the condition of rest to that of movement, the latter state may be assumed to exist in all cases of machinery. The condition of quiescence may be considered as occurring in statical problems of the stability of structures.

With respect to the materials forming rubbing surfaces, it has been found that the softer substances produce more proportionate friction than the harder, and, of course, in those the limits of abrasion are sooner reached than in the latter.

When unguents are used, the surfaces may be merely greasy, or, from the thickness of the lubricating matter, and the small insistent pressure, a complete film of this matter may be interposed between the rubbing parts. In the former instance, the resistance varies as little as possible from that due to the dry surfaces. In the latter, the surfaces in contact are practically not those of the hard materials, but two surfaces of hard material with one of the interposed grease. Hence, under these circumstances, the friction is found to depend more on the kind of unguent than on the nature of the bearing. Thus, surfaces of wood on wood, wood on metal, metal on wood, and metal on metal, when abundantly supplied with grease, have nearly all the same coefficient of friction, which varies between 0·07 and 0·08, when hog's lard or oil is used, and rises to 0·10 with tallow. With axle bearings of the usual materials, and greased in the usual way, the coefficient varies from 0·10 to 0·19 of the insistent pressure.

Much depends on the adaptation of unguents to the circumstances under which they are to be used. The softer greases, as oil, hog's lard, &c. diminish the resistance under small pressures more than under high pressures. The harder greases, as tallow, soft soap, and mixtures of grease and plumbago, produce less effect with small pressures than with large ones. The cause of this evidently exists in the different facilities with which the unguents can form a perfect separating film between the surfaces of contact, or are by an increase of pressure squeezed out so as to leave those surfaces in effect merely greasy. With each kind of lubricating matter there must evidently exist a certain pressure per square inch of bearing surface, at which the unguent forms a perfect film between the rubbing parts. This is the state producing the minimum of resistance. An increase of pressure, by squeezing out this unguent, increases the coefficient of friction; and a diminution of pressure, by allowing the viscosity of the unguent itself to affect the result, may also add to the proportion of resistance.

The resistance produced by the viscosity or adhesiveness of the unguent itself is generally of too small magnitude to be taken into consideration in large machinery, but in watch and clock mechanism this resistance becomes of considerable importance.

Professor Moseley, of Cambridge, first made known a method of computing the effect of friction, which is of great practical importance. It may be briefly illustrated thus: If a body, M, Fig. 1008, be pressed upon a surface A B by any vertical force P, this force may be represented in direction and in amount by the vertical line M P, containing as many units in length as there are units of weight in the pressure P. Similarly, the friction due to this pressure, and which is dependent for its proportion to P on the nature of the surfaces in contact, may be conceived to act parallel with the surface A B in a direction opposite to that of any force tending to slide M along A B. Let this friction be represented in direction and amount by the line M R, which has the same proportion in length to M P that the resistance of friction has to the pressure P. Complete the parallelogram M P F R, which has these two lines for its adjacent sides, and draw its diagonal F M. Now the angle which F M makes with M P is determined by the proportion of M R to M P; that is, this angle is dependent on the friction between M and A B. In fact it is that angle the tangent of which is the coefficient of friction for these two surfaces. This angle F M P is called by Professor Moseley the *limiting angle of resistance*, and its property is, that if any oblique pressure be applied to M, this pressure, however great it may be, will not cause M to slip, unless it make with the perpendicular a greater angle than the limiting angle of resistance; and if it does thus make a greater angle than F M P, it will, however small it may be, cause M to slip on A B. This principle is of the highest value in mechanical problems, enabling questions of the stability of structures and of the useful effect of machines to be solved with facility and accuracy. If the line F M revolve about M P, it will describe an imaginary conical surface. This is the *cone of resistance*. Any pressure the direction of which lies within this cone will be resisted by M up to the point of crushing, and if its direction lie without this cone, it will not be resisted by M, but this body will slide on A B. [See BRIDGE, *Sec.* 11.]

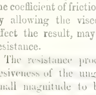

Fig. 1008.

A table of the limiting angles of resistance accompanies many tables of the coefficients of friction. When not so given they may be found from any table of natural tangents, by seeking that angle whose tangent is equal to the coefficient of friction of the bodies in question.

From the brief illustration given above it is evident that when a single force, or the resultant of any number of forces, acting on any body, as M, is inclined exactly at the limiting angle of resistance for M and A B, then this force must be just on the point of causing the body to slide on A B. This, then, is the state bordering on motion, which enables us to determine the relation between the forces impressed on a body or system of bodies held by these forces in a state of rest, and allowing in this relation for the effects of friction. Hence, in all problems relating to the balance of forces in equilibrium, we know that the resultant, or joint effect of those forces, must be inclined to the surface on which motion is on the point of taking place, exactly at the limiting angle of resistance.

As an illustration of this application, let us suppose a lever A B, turning on an axis or pivot 3 inches in diameter, and distant 12 inches from one extremity of the bar and 8 inches from the other, to be so held in equilibrium by two forces, P and W, that P is just on the point of preponderating and overcoming W.

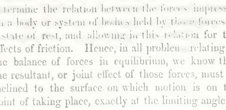

Fig. 1009.

It is required to determine the relation between these two forces in this state, taking friction into consideration. Now, since the axis is on the point of turning on its bearings, it is evident that the resultant of these two forces cannot pass through the centre of this axis, or it would produce no tendency to motion; but it must pass through such a point in the axis, that its direction, when prolonged, may make with the plane of junction between the axis and its bearing an angle equal to the limiting angle of resistance corresponding to the materials of which these parts are constructed. Suppose this angle to be 30°. Then, by construction, we proceed thus. Draw the axis to a large scale, as in Fig. 1009; then, since both forces act vertically, their resultant must also act vertically, and it must evidently act on the side of the centre nearest to the preponderating force P. Draw the vertical radius C O; make the angle C O E equal to the limiting angle of resistance, and prolong E O to cut the circumference of the axis in a point S on the side of P. Through S draw a vertical R S; then the angle R S O equals the limiting angle of resistance. Then the point R, where the line S R cuts the axial line of the lever, is the point through which the resultant acts, and therefore from which the moments of these forces are to be measured. Now we see that if instead of the two forces P and W, a single force were acting parallel to the directions of P and W, that is vertically downwards on the point R in the axis, this force would press the axis downward on the point of its bearing S, in a direction R S inclined to the surface of junction at S, at an angle R S O, equal to the limiting angle of resistance. This single force would therefore be on the point of moving the lever downward on the side of P, that is, it would be on the point of producing the same action as P and W. This single force, which could be substituted for any number of forces, and produce singly by itself the same effect which those forces were capable of producing altogether, is termed the resultant of those forces. If the forces P, W, instead of being parallel in direction, had been inclined to one another, an analogous, but more complicated process must have been adopted to ascertain that point of the circumference of the axis on which the whole resultant pressure might be conceived to act. When found, we know that at this point the direction of this resultant makes with the surface of bearing an angle equal to the limiting angle of resistance. Into this problem, however, it is not necessary to enter, as our only object is to explain the general application of the principle made known by Prof. Moseley, and to deduce at the same time the actual effect of friction in modifying the conditions of equilibrium.

Had this question been solved as a pure question, neglecting the effect of friction, the moments of P and W would have been measured from the centre O; and these forces, when in the state of equilibrium, would have had magnitudes inversely as the distances from O of their points of application; that is, P would have been 8 and W 12. But when friction is taken into account, the moments are measured from a point nearer to the preponderating force than the centre of motion. By actual construction the point R would be found to be 0·75 inch nearer to P than the centre O. That is, the distance P R is 0·75 inch less, and W R is 0·75 inch more, than the corresponding distances of P and W from O. Therefore these forces, which are in magnitude inversely as their distances from the point of application of their resultant, are found to be P = 8·75 and W = 11·25. But these forces are still only in equilibrium, though P is 0·75 more and W is 0·75 less than they were computed to be when the effect of friction was neglected.

From this we see that the effect of friction is to increase the amount of force necessary to be applied to produce any mechanical effect; or, which is the same thing, to diminish the useful effect W capable of being yielded by any applied force P. Had W been on the point of preponderating, the angle O S R would have been drawn on the other side of O S, and then we should have had the force W necessary to overcome P, increased by the amount due to the friction also to be overcome.

This effect of friction is quite general. The resistance due to this action may in all cases be regarded as so much additional power necessary to be expended to produce a given effect, or as so much less effect produced by the action of a given amount of power.

So far the statical effects of friction. In dynamical problems we have to remember that friction produces a constant retarding force, which, in order to the continuance of any motion, must be overcome through a space proportionate to the extent of such motion, by the expenditure of a corresponding additional quantity of working power. Now the amount of work necessary to be expended to overcome this resistance, is measured by the product of the actual magnitude of the resistance multiplied by the space through which it is overcome. It may be diminished, therefore, either by lessening the actual magnitude of the opposing resistance, or by diminishing the distance through which it has to be overcome. To accomplish the first, the parts should be made as light as possible consistent with strength, so as to diminish the weights on the bearing surfaces; and in cases where it is practicable, the driving power should be applied on the same side of the centre of motion as the resistance to be overcome. This important principle, also made known by Prof. Moseley, will be rendered clear by applying the conditions of the problem in Fig. 1009 to the case of a lever of the second order, instead of (as in the Figure) to a lever of the first order. The second means of diminishing the loss of work due to friction, by diminishing the space travelled over, leads to the axes or pivots of wheels and levers being made as small as possible: not to lessen thereby the amount of resistance, but to lessen the space through which the rubbing surface of the axis turns, and through which the resistance has therefore to be overcome. In both cases the judicious application of unguents is obviously an important element in the question.

In some cases the loss by friction is lessened by causing the bearing parts to rest, not on fixed surfaces, but on the circumferences of wheels or rollers free to turn on their axes. There is then no rubbing between the first bearing and the *friction wheel* or roller, the first simply rolling upon the second and turning it round with itself. The rubbing is confined to the pivots of these friction-wheels, and the spaces through which they move are obviously less than the spaces moved through by the original axis, in the same proportion that the circumference of the pivot of the friction-wheel is less than the circumference of the wheel itself. This method is applied in the apparatus well known as Atwood's Machine. It has also been applied to carriage axles, to railway wheels, to the pivots of large capstans, &c.

In large metal structures, as bridges, the expansion and contraction of the material must be allowed for by giving freedom of motion to the ends of the structure. But were this motion only allowed to take place by the sliding of the ends of the structure on the surfaces of its piers or supports, the enormous friction produced by such vast weights insistent on such rough surfaces, would practically render the ends almost rigid, and the force produced by changes of temperature would be exerted to crush or tear asunder the structure itself. To avoid this, it is usual to cause the ends to rest on balls or rollers, free to turn under the structure, thus substituting an entirely rolling contact for one of rubbing surfaces. [See Bridge, Secs. V., VI.]

FRIT. See Glass—Enamel.

FUEL. The chemical combination of two substances whereby heat and light are produced, constitutes the process of combustion in its extended sense. [See Combustion.] The most common, as well as most ancient example of combustion, is where the oxygen of the atmosphere is made to combine with some substance easily procurable, such as wood, turf, pit-coal, &c. Such substances are known by the name of *fuel*, from the French *feu*, fire, which is derived from the Latin *focus*, a hearth or fire-place.[1]

The process of combustion is employed either as a source of *heat* or of *light*. The nature of the process and of the substances employed, together with the practical arrangements for carrying it on, render it impossible, or at least not desirable, to attain both objects at the same time, hence the production of heat and of light form distinct branches of industry. [See Candle—Gas Lighting—Lamp, &c. for the production of light; and for the production of heat, see the present article—Coal—Carbon—Coke—Combustion—Stove—Warming, &c.]

Most of the operations in the Useful Arts require, directly or indirectly, the application of artificial heat, and the means of obtaining it are of first-rate importance in every manufacture. The political power of a country such as Great Britain is due, not to her army or her navy,—for these are defensive, not productive,—but to the great development of her manufactures; and this is in great measure dependent on an abundant supply of fuel easily procurable at a cheap rate.

Wood. The carbonaceous parts of plants, whether found upon or under the surface of the earth, are peculiarly adapted for supplying an easily combustible fuel. This source is extensively distributed, and is in a constant state of reproduction. The trunk, roots, and larger branches of trees, form what is called *wood fuel*, or simply *wood*. In this variety of fuel there are three different substances to be considered: 1, the *woody fibre*, a compound of carbon, hydrogen, and oxygen, which constitutes the cells and vessels of the plant, and forms its chief bulk; 2, the *sap*; and 3, the *water*, existing in the vessels of the plant. Recently felled wood contains all three constituents: the last two are combustible, and produce heat; the third is converted into vapour, and expelled at the expense of the heat produced during the combustion of the other two. Woody fibre and water are common to all kinds of wood: the differences in woods are in the sap and in the density. In coniferous woods the sap is resinous; beech and birch contain extractive; oak contains tannin: the constituents of the sap, however, form a very small proportion of the whole bulk of the wood. The proportion of water is greatest at the time of the flowing of the sap, and least when the growth of vegetation is less rapid; hence wood should be felled in the winter, unless indeed it be cultivated more for the sake of the tannin in the bark than the wood, or the spot where it grows be inaccessible at that season. The amount of water differs in different species of wood, but in general in recently felled wood, from [illegible]th to $\frac{1}{2}$ of its weight is water, and in that which is commonly used for fuel, above $\frac{1}{3}$d: the quantity, however, greatly diminishes by exposing the wood to the air in a dry place. Thus, in 10 or 12 months, 100 lbs. of wood are reduced to 80 lbs. by the evaporation of the water, the value of the same as fuel being of course greatly increased.

Long immersion in water is injurious to wood in consequence of the loss of soluble matter dissolved out by the water, thereby diminishing its volume and heat producing power: 1 cubic foot of wood may lose 1 lb. in weight by being floated from the forests down the streams, as is done for convenience of carriage in the Black Forest, Salzburg, &c.

When wood has been burnt, an incombustible residue or ash remains, consisting of earthy and alkaline salts, and varying from [illegible]th to [illegible]th of the wood.

The ultimate composition of different woods does not vary so much as might have been anticipated from their very different properties. Hydrogen and oxygen are contained in woody fibre in the same proportions as those in which they unite to form water, viz. 1 : 8; and this relative proportion is exceeded by the hydrogen in the different woods and in a variable manner.

Peat. This substance is of great importance as fuel. Ireland contains about three million acres of bog, and companies have been formed for obtaining valuable products from the peat by distillation and other means, such as paraffine, paraffine oils, &c., with what success will be seen under Peat, App. Small deposits of peat are found in almost every country, but districts of immense extent occur in Holland, North Germany, the Grand Duchy of Hesse, &c. In Germany, on the Rhine, the peat is cut by means of common spades into the shape of thick bricks, which are placed to dry on some kind of support. Care is taken to separate the peat of the upper part of the layer, which is young and fibrous, from the heavy and more abundant lower peat. In Holland the preparation of peat resembles the process of brick-making. The peat is scooped out with spades, as long as it is possible to do so, and when the spongy mass becomes too thin, an instrument is used consisting of a sharp iron ring fixed upon a handle, and perforated with small holes for supporting the bottom, which is formed of net or of cloth, so that on scooping up the muddy peat, the water drains off. The mud thus collected is converted into a homogeneous mass by treading with the feet, stirring about with rakes like mortar, and picking out the stones: it is then spread out evenly in layers, 1 foot thick, in large wooden boxes, such as are used for slaking lime, that the water may run off and the mass become dry. The boxes are previously strewed with stamped hay to prevent the peat from adhering to the box, and after some days, when the mass exhibits a certain consistence, a number of women strap flat boards like snow-shoes to their feet, and stamp it down until sufficiently compressed not to take an impression from a common tread: it is lastly stamped with beaters until the surface is uniform. The cake, now 8 or 9 inches thick, is divided by means of long laths into squares of about 4 inches, and these are gradually removed. The thickness of the cake is the length of the bricks, which are kept upright. In drying the cakes, the first one taken out is laid transversely upon the second; the third is laid upon the fourth, and so on; this order being reversed when the pieces are piled up.

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[1] Such derivatives are not uncommon in the French language, as *jeu* from *jocus*, *lieu* from *locus*.

In some places the peat mud is scooped out with buckets on to a dry place, and when the water has drained off, it is made into bricks with moulds. Too large an amount of water in the peat may completely destroy its value, and render it incapable of being piled. Its value increases in rapid proportion to its dryness, density, and firmness. If it possess these properties only in an inferior degree, it suffers by carriage and by keeping, the upper layers of the heap compressing and breaking the lower layers, which thus become valueless. The porosity and brittleness of peat prevent its application in all cases where fuel and matters to be heated are piled up to a height one above the other. Besides this, dense peat compresses in a like bulk much more combustible matter than porous peat. Hence the use of presses for condensing the peat. In one experiment, a brick weighing 8 lbs. lost 2·5 lbs. of water under the press. The longer peat is allowed to dry in appropriate sheds, the more it will improve as a heating agent. In some cases the quantity of ash yielded by peat is so large as to render the peat useless as fuel. This ash consists, *first*, of salts peculiar to vegetable matter, and which have not been dissolved out by the bog-water; and *secondly*, of the earthy matter collected during the deposition of the peat. Indeed, peat of various districts has been found to contain from 1 per cent. to one-third of its weight of ash. Carbonates of the alkalies are never found in it, but phosphates, sulphates, &c. In 100 parts of ash Einhof found 15·25 lime, 20·5 alumina, 5·5 oxide of iron, 41 silica, 15 phosphate of lime, 1·75 common salt and gypsum. Schubler found 34 per cent. of phosphates in the ash of peat from Schwenningen, thus making it valuable as a manure. The ash is otherwise injurious as causing dust and taking up much room, decreasing the quantity of combustible matter, and in smelting processes acting chemically.

Coal has already been treated of under that head: its value as a fuel will be more fully considered in the present article: Coke and Charcoal have been noticed in the article **Carbon**. **A description of fuel made from a mixture of coal-dust and pitch,** or coal-tar, and known as Patent Fuel, was introduced some years ago. The advantages of this kind of fuel are economy of money and of space:[1] for waste and refuse coal was used, such as from its pulverulent state is unfit for the ordinary purposes of combustion. This invention, although new to us, is an ancient one, for the Chinese have been accustomed for ages to mix their powdered fuel with a compost of soft clay just sufficient to make it cohere; cow-dung or other refuse vegetable matter is also used: balls are then formed of this mixture, which are dried in the sun or open air. This method is not adopted on account of the scarcity of fuel, for coal is abundant in China: but the Chinese, unlike the English, know how to take care of it. These fire-balls during combustion give out very little smoke: they are largely manufactured in the coal districts, and are distributed by canal over a large portion of the empire. Powdered fuel mixed with clay is also sold in some parts of continental Europe as *combustible bricks*. Peat has also been converted into patent fuel: by Hill's process the peat is distilled dry, and the pyroligneous spirit and tar collected: the tar is converted into pitch, which is mixed while hot with the peat charcoal. Wylam's method of making patent fuel involves several distinct branches: 1st, the separation of coal tar by distillation into naphtha, dead oil, and pitch; the pitch is mixed with small coal and moulded into bricks, as will be described presently. 2. The naphtha is rectified, and sold as such. 3. The dead oil is converted into ivory black, and is also used for other purposes. 4. The pitch, having become hard, is ground under edge stones, and mixed with small coal in the proportion of 1 to 4. This mixture of coal and pitch is carried up into a large hopper, from which it gradually passes into the receivers, M M, Fig. 1010, at the bottom of which a pair of plain

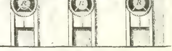

Fig. 1010.

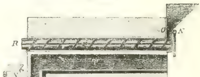

Fig. 1011.

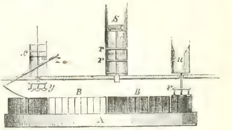

Fig. 1012.

rollers O, Fig. 1011, are kept in motion by the shaft N, Fig. 1010; and in this way a regular supply is thrown into the retort R. An Archimedean screw Q, Fig. 1011, inside the retort, is also made to revolve by means of the shaft S. The retort is kept at a dull red heat by the hot air of the flue T, and the fuel passes through the whole length of the retort, which is about 15 feet, in about 3 minutes. The mass of coal and pitch is discharged at the opposite end of the retort in a pasty state, and carried by an endless chain into the receiver s, Fig. 1012, where it is kept in motion by the arms *x x*, so as to prevent it from hardening into lumps. From this cylinder or receiver it runs into large moulds, where it is subjected to a heavy pressure in the following manner: A is a movable oval table upon which the moulds B B are fixed; s the vessel which receives the fuel paste; *u* and *x*, two cylinders similar to the cylinders of a steam-engine, but worked by water; *v y*, the pistons, to which two rams are attached, each having 6 arms fitting accurately into the moulds B B; and *z* is a lever, worked by means of the piston *y*. The moulds are filled from the vessel s as the table is made to revolve by the movement of the lever *z*. As the moulds approach the cylinder *u* the piston descends and compresses the fuel with enormous force; and after the piston rises, another set of moulds take their places, while the piston *y* of the cylinder *x*, having descended at the other end of the table, the six bricks are forced out of the moulds, and are received below ready to be stamped with the maker's name. The composition of these bricks appears to be—

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[1] Its importance in this respect may be judged of from the fact that the Mammoth Steam packet, of 1,000 horse power, requires for one journey 81,881 cubic feet, or 2,240 tons of coal.

Coke	Carbon	61·67
	Ashes	7·08
Gaseous matter		31·25
		100·00[1]

The relative values of fuel is a very important inquiry. Different kinds of fuel produce very different amounts of heat, and various methods have been adopted for ascertaining their maximum effect. To find the theoretical effect of any fuel, we must know the *quantity* of heat which a certain amount of such fuel is capable of producing, and the *time* required for effecting that object. These two points furnish the *heating power*, on which its value as fuel (in conjunction, of course, with its market price) depends. But as heat cannot be weighed or measured, it is impossible to ascertain the *quantity* of heat produced by a body during combustion; but it is not difficult to ascertain the effect of one kind of fuel compared with another kind; how much one kind exceeds or falls short of the other. This gives a relative value to the fuels, although the actual quantity of heat produced by each is altogether unknown. One of the methods of making this comparison is to cause the whole quantity of heat evolved by the fuel under examination to act upon a third body, which producing different effects under the action of different kinds of fuel, thus affords a standard of comparison. Lavoisier and Laplace caused the heat of their calorimeter to act upon ice, and they measured the heat by the quantity of ice melted. Rumford used water instead of ice, and measured the quantity of heat by the increase of temperature in a given quantity of water. Both methods are similar, if we bear in mind that the same quantity of heat which will melt 1 lb. of ice at the zero of the centigrade thermometer, is just sufficient to raise the temperature of as much water 79° Cent., or, what is the same thing, to raise 0·79 lb. of water 100° Cent. When it is also remembered that an equal weight of aqueous vapour, whatever its temperature and tension, is always formed from one and the same amount of heat, and, consequently, always contains the same quantity, and that the quantity of heat which water at 100° Cent. absorbs or renders latent in order to become vapour, would be 5·5 times sufficient to heat the same weight of water from 0° to 100° Cent.: hence, it is easy to calculate how much water would be converted into vapour by the heat required to melt 1 lb. of ice: it is found to be the 5·5th part of the same lb., or in other words, it is capable of converting into vapour 0·154 lb. of water.

Despretz and Welter found that those quantities of a combustible body which require equal amounts of oxygen for combustion, evolve also equal quantities of heat, and this was made the measure of the heating power. [See COMBUSTION.] Indeed, considering that the heat evolved must bear some relation to the mass of the body burned, so the oxygen may also be regarded as the combustible as much as the fuel with which it combines. When, therefore, oxygen burns by means of carbon, wood, hydrogen, &c., the heat evolved must increase with the quantity of oxygen consumed. On this supposition Berthier founded a practical process for detecting by one experiment the quantity of oxygen required for combustion, and thus the heating power of the combustible. This process is, to heat to redness a weighed quantity of the combustible with a large excess of pure litharge, until the combustible is completely consumed by the oxygen of the oxide of lead, as it would be by the oxygen of the air. Every equivalent of oxygen thus consumed leaves an equivalent of reduced metallic lead, and it is only necessary to weigh this reduced lead in order to discover the amount of oxygen consumed, and consequently the heating power, the object being merely a comparison of the relative powers of the different kinds of fuel.

The lighter kinds of woods contain more hydrogen than the heavier, so that the first stage of their combustion with flame is increased at the expense of the second—viz. the incandescence of the charcoal; hence they burn with greater facility, and evolve their heat in a shorter time than the hard woods; hence, also, lighter woods are more combustible than harder, and give out more heat, inasmuch as 1 equivalent of hydrogen requires 3 times as much oxygen (evolving 3 times as much heat) as 1 equivalent of carbon.

The state of division of a fuel is a point of im-

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(1) Appendix to Knapp's Technology, by Dr. E. Ronalds and Dr. T. Richardson. Vol. I. 1848. The work itself has also furnished us with considerable information in the preparation of this article.

portance. A cwt. of wood in the state of shavings will expose a much greater amount of surface to the air than when in the form of a log. Numerous portions of wood will be burning at one time in the former case, while in the latter the surface is only, or chiefly acted on; and while the log will maintain a moderate temperature for hours, the shavings may produce a red heat in the sides of the furnace in a few minutes. But as the amount of combustion, or quantity of fuel, consumed in a given time, increases by a state of division, so if this state is increased beyond a certain limit, it acts in an opposite manner, and destroys combustion altogether. Thus saw-dust, charcoal, or peat in powder, crushed coal, &c., cease to be combustible under ordinary circumstances, because the small particles lie so close together that the air necessary for combustion cannot penetrate. If coal be of a caking quality, its dust can be converted into compact coke; but fuel which falls to pieces in the fire without caking, has many of the objections of powdered fuel. The pulverulent waste from peat, wood charcoal, and pit-coal may now be converted into patent fuel, and on the continent small fuel is often used in glass-works and for boiler fires, the grate-bars having been previously covered with lumps of sandstone, limestone, &c., to prevent the powder falling through the grate, and to distribute the supply of air through the fuel. An ingenious application of clinkers to the same purpose is described in the article COPPER, p. 428.

The quantity of heat obtained from fuel in the useful arts and manufactures falls very far short of the theoretical value. A considerable portion of the heat is either not evolved, or is lost without any useful effect. The application of fuel to practical purposes is called *heating* or *warming*, see WARMING,] and its object is to evolve the heat from the fuel as completely as possible, and to apply it without loss to the purpose it is intended to serve, as in the processes of boiling, roasting, smelting and forging operations, the warming of dwellings, &c.

Some valuable information respecting fuel, especially as regards the coals of our own country, is contained in the reports "on the coals suited to the steam navy, by Sir H. De la Beche and Dr. Lyon Playfair."[1] This inquiry was undertaken at the public cost, on the establishment of a steam navy, and the reports are published under the authority of the Government. The following is an abstract of these reports, and in the Appendix will be found some statements based on further experience of the subject.

Considering the purposes to which the coal was to be applied, the chief test of the value of any particular coal was its *evaporative power*, or power of converting water into steam. Thus, if a given weight of coal in a certain time converted a larger portion of water into steam than a similar weight of another coal, the evaporative power of the first would be greater than that of the second. It is shown, however, by this inquiry, that the true practical value of coals for steam purposes depends upon a combination of qualities which could only be elicited by careful and continued experiment. Their qualities, so far as regards steam-ships of war, are stated as follows:—1. The fuel should burn with a quick action, so that steam may be raised in a short period. 2. It should possess high evaporative power; that is, be capable of converting much water into steam with a small consumption of coal. 3. It should not be bituminous, lest so much smoke be generated as to betray the position of ships of war when it is desirable that this should be concealed. 4. It should possess considerable cohesion of its particles, so that it may not be broken into too small fragments by the constant attrition which it may experience in the vessel. 5. It should combine considerable density with such mechanical structure that it may easily be stowed away in small space; a condition which, in coals of equal evaporative values, often involves a difference of more than 20 per cent. 6. It should be free from any considerable quantity of sulphur, and should not progressively decay, otherwise, in either case, it is liable to spontaneous combustion.

The above conditions are never united in one coal. Anthracite, for example, has very high evaporative power, but not being easily ignited, is not suited for quick action. It has great cohesion in its particles, and is not easily broken up by attrition, but it is not a caking coal, and, therefore, would not cohere in the furnace when the ship rolled in a gale of wind. It emits no smoke, but from the intensity of its combustion, causes the iron of the grate-bars and boilers to oxidize, or waste away, rapidly. Thus, with many advantages, anthracite has several defects which under ordinary circumstances preclude its use. It was thought that the above conditions might be united in some of the fuels prepared from coals possessing the various qualities, after the manner of patent fuels, and with this object experiments were directed to be made with the view of preparing such a fuel. Hence, in order to obtain a knowledge of the coals of different districts, Wales was first selected for examination, as producing coals of all kinds, varying from bituminous to anthracite. The result of these experiments was not favourable. The cementing tar, though partially carbonized by the heat of the coking-ovens in which the prepared fuels are heated, was so much more combustible than the dense and difficultly burning anthracite, that the latter remained after the combustion of the former, and either accumulated on the bars in the state of powder, obstructing the draught, or falling through the grate escaped combustion. If thrown again on the fire, it choked the air-way and impeded the proper action of the fuel. The evaporative power of the fuels thus prepared was found to increase according as the proportion of fixed carbon was augmented; but this would appear to arise from the fuel then assuming more of the characters of the anthracite or coke from which it was made. The results of the experiments indicated the necessity of keeping a uniform character in the fuel manufactured.

In the selection of the coals for trial careful

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(1) Date of the first Report, 1848; of the second, 1849.

inquiries were made at the different ports in the neighbourhood of the coal-fields as to the kind of coal exported for steam purposes. Information from steam-ship companies, in the habit of using the coals of that district, was collected, and the local character of the fuel was ascertained. Circulars were then forwarded to the owners of such coals, explaining the object of the inquiry, and requesting them to furnish 2 tons for experiment. In most instances the coal was sent, but in a few cases the owners declined to do so; and as it was contrary to the spirit of the inquiry to report on the merits of coals contrary to the wishes of the owners, no coal was examined except such as was delivered free of expense to the commissioners, under the certificate of the owner or his agent.[1]

The method of testing the cohesive power of the coals, was by means of a wooden cylinder, 3 feet in diameter, and about 4 feet long, each end with a bearing or gudgeon attached to it; in the interior were fixed 3 shelves, each 6 inches wide, tending to the axis, for the purpose of forming a lodgment for the coals, and of carrying them up towards the top of the cylinder during its revolution, thus ensuring a certain amount of fall. The coals being put in at a door at one end, the cylinder was supported by a tressle at one end, the other gudgeon resting on a block let into the wall, and motion was communicated by a band passing round its circumference. The coals to be tested were first broken to the size employed in the experiments on their evaporating power, then thrown on a sieve, the meshes of which were 1 inch square. Of the coals left on the sieve 100 lbs. were put into the cylinder, which was then turned a certain number of times. The coals were again sifted on the same sieve, and the weight remaining gave the per centage of large coals found in the tables. These values are the mean of 2 trials with each coal, with 50 revolutions.

Each coal was subjected to experiment for 3 successive days, the draught being differently arranged for each day, either in the proportions of 4 : 5 : 8 or 1 : 2 : 4. In this way it was easy to ascertain when the gases escaping from the coals were most economically consumed. The coals most liable to be influenced by the different adjustments for the admission of air, are those which from their bituminous characters are most apt to generate a large quantity of gaseous products on the first application of heat, such as the coals from the Northumberland, Durham, and Lancashire coal-fields; and it was, therefore, found that the experiments made with them under different areas for the admission of air, vary much more considerably than the less bituminous coals of the South Wales coal-field. It was soon found necessary in the highly gas-giving coals, such as the Cannel coal of Wigan, to allow air to enter behind the fire-bridge, so as to complete the combustion of the escaping gases.

The experiments were conducted at the College for Civil Engineers, at Putney, by Professor John Wilson and Mr. J. Arthur Phillips, assisted by some other gentlemen of scientific attainments. The boiler-house is described as a rectangular building, 35 feet in length, and 16 feet 6 inches in breadth. The brickwork of the boiler is built against one of the end walls; its width being 7 feet 8 inches, and length 15 feet; the side is separated from one side wall by an interval of 18 inches, for the purpose of preventing loss of heat from the boilers by conduction through the external wall; by this means, also, ready access is gained to the base of the chimney H, Fig. 1013. The tanks E F for supplying the boiler with water, are made of wrought iron plates, riveted together and placed outside the roof, the cast-iron pipe which supplies them with water being brought up inside the building to defend it from frost. The extremity of the pipe is furnished with the means of directing the flow of water into either tank at pleasure, and a two-way cock, *b*, connected with the tanks, directs in a similar way the supply from them to the boiler. A cock on the feed-pipe a short distance below this regulates the quantity of water admitted to the boiler. The boiler is cylindrical in form, 12 feet in length and 4 feet in diameter, with flat ends, and an internal flue 2 feet 6 inches in diameter, in one end of which the grate is placed. This is the usual form of *Cornish boilers*. The flues are on the *split* or *bridle* draught plan, in which the column of heated air, after leaving the fire, passes through the internal flue to the rear of the boiler, where it divides, returning along the outside of the boiler on both sides to the front, the two branches, which are each 2 feet 6 inches deep, then turn down at right angles to their former course, and uniting under the boiler in the bottom flue, which is 2 feet 6 inches wide, traverse its whole length again and finally enter the base of the chimney, after exposing, during a course of about 36 feet, an area of 197·6 square feet of boiler surface to the heating action. In the horizontal part of the flue at K, just before entering the chimney, a damper is placed sliding vertically in a cast-iron frame, which is worked by means of a rod passing through a stuffing-box and attached to a cord K′ carried over two pullies, and furnished with a balance weight, so that a person standing near the fire-door can easily regulate the amount of draught. The internal dimensions of the chimney, 182¼ square inches; the whole height, 35 feet 6 inches. Apertures were made in the chimney about 6 feet from its base, for the purpose of making observations on the temperatures of the currents, and of obtaining samples of the gases for analysis. Openings were also made at the end of each of the side flues, and at the base of the chimney, for the purpose of drawing out the soot at the end of each set of experiments. The floor of the flues is laid in fire-tiles, to facilitate its removal. When the furnace is in action, the apertures at the end are closed, and loss of heat prevented by means of stone doors 4 inches thick; then an interval for air about 1 inch thick; and, finally, cast-iron hanging doors lined with fire-clay. The fire-grate is 2 feet 6 inches wide and 2 feet long, thus giving an area of 5 square feet of grate surface; the bars are ¾ inch in thickness, with [illegible] inch spaces between them. In the front end of the grate, near the fire-door, is an iron plate called a *dead-plate*, for the purpose of gradually heating the coals; it is 10 inches wide and slopes down to the grate; beside this is another plate 8 inches wide, sloping upwards to the fire-door, contracting it in its width to 15 inches, which is the width of the aperture for the introduction of fuel. The fire-doors used for closing the entrances to the grate and ash-pit, were on Mr. Sylvester's plan, and well adapted for preventing the loss of heat, regulating the direct supply of air to the fire, and the convenient application of fuel. In this arrangement, *c d*, Fig. 1014, is a large cast-iron plate let into the brick-work, and having 4 projecting brackets, *e e*, *f f*, in which are secured the ends of stout cylindrical bars which are to carry the doors. The apertures to the grate and ash-pit are surrounded with an iron rim or edge, about ½ inch wide, the lower part being continued backward along the plate, forming a kind of guide, *g h*. The fire-door, which exactly resembles the ash-pit door, consists of a rectangular cast-iron box, having its edge ground so as to fit accurately the iron rim before described, and the interior is filled

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[1] In the article COAL, p. 384, the elementary analysis and economic value of some of the coals examined are exhibited in a tabular form. See also the Table at page 722.

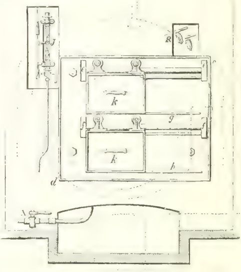

Fig. 1014. FIRE-DOORS OF THE FURNACE.
The dotted circles show the form of the boiler.

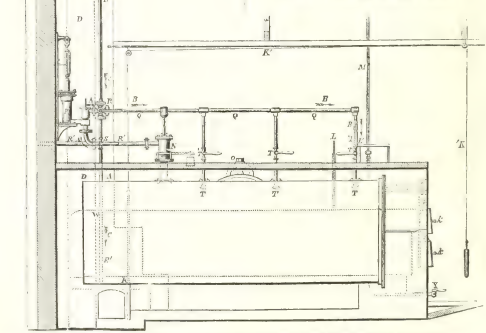

Fig. 1013. THE BOILER AND ITS ASSOCIATED APPARATUS USED IN THE EXPERIMENTS ON STEAM-COAL.

with, first, a layer of fire-brick, then a space for air, and then another thickness of fire-brick, which effectually prevents loss of heat. The top of the door has projecting ledges, forming the checks for two friction wheels, *l l*, which run on the cylindrical bar already mentioned, so that when the door is drawn sideways by means of the handle K at its back, the wheels roll along the bar, the lower part of the door sliding at the same time closely along the ledge or guide *g*. The two sides of the aperture are sloped gradually, so as with the lower edge to project more at bottom than at the top; this causes the weight of the door to act in keeping the surfaces in contact. The boiler has three safety valves, one of which is loaded directly, and has an area of 5.4 square inches, and two smaller steelyard valves, each having an area of 2.07 square inches. In the experiments, the boiler was worked the first two days with a pressure of 1lb. per square inch, and generally on the third day with a pressure of 3 lbs. on the inch. The thickness of brickwork at the crown of the boiler is 4½ inches, and the valves were brought up on a level with it and then paved, thus forming a large platform, and affording convenient access to the different thermometers and apparatus. Openings were made into the side flues in about the middle of their length, in which were fixed iron tubes closed at the lower ends, and containing oil in which the thermometers were placed for giving the temperatures; a similar tube was inserted at K in the base of the chimney, and another in the boiler at L, to give the initial temperature of the water in it.

The method of conducting the experiments is now to be described. Supposing the water in the boiler to be cold; and to stand about 1 inch below the normal level, the fire was lighted and the steam got up in the afternoon of the day preceding the commencement of the experiments. The fire was then allowed to burn out, when the fire and ash-pit doors and the damper were all closed. The next morning the first thing done was to open the safety valve to equalize the external and internal pressures, and then sufficient water was let down from the tanks to raise that in the boiler to the normal level. The depth of the water in the tanks was then gauged, and the first observation of its temperature made. The ashes, cinders and soot, were next cleared out, and after noting the temperature of the water in the boiler, the fire was lighted with a weighed portion of wood, and the exact time was then observed. The coals were then gradually added till the fire was of the proper size and form. The form of fire was slightly varied according to the kind of coal employed, the object being to burn the coal to the best advantage with as little smoke as possible at the chimney. The observations of the temperatures of the two side and escape flues, and of the water in the tanks, then succeeded each other at regular intervals of about one hour each. When the steam raised the safety valve the time was observed and entered under the heading *steam-up*. The damper was adjusted as soon as the fire was sufficiently established, and was not disturbed during the day, except under peculiar circumstances. When, by evaporation, the water had sunk about 1 inch below the normal level, the deficiency was supplied from the tanks above; or, by the plan afterwards adopted, the water was allowed to flow in continuously, so as to maintain the water in the boiler at a constant level. The fire was supplied with coals in pieces not exceeding 4 lb. weight each, and not more than one or two shovelsfull at a time, and were constantly spread evenly over the fire; but in the case of anthracite, it was found that too sudden application of heat caused the pieces to split and fall through the bars. They were, therefore, gradually heated on the dead plate before being put on. With the bituminous coals a preparatory process of partial coking on the dead plate prevented their fusing and caking in the fire, which would have impeded the passage of air through the grate, besides giving better opportunity for burning the smoke and gases by passing them over a large surface [illegible]. The duration of the experiment was reckoned from the time the steam was up to about ½ h. after the last application of fuel, after which the fire was allowed gradually to burn out, when the damper, and furnace and ash-pit doors were closed. During the day, ashes were thrown up in small quantities from time to time, when the fire was burning clear and well. The weight of coals consumed was then ascertained, by deducting the weight left from the quantity provided for the day's trial, when the experiment terminated. The next morning, when the level of the water in the boiler was adjusted by turning down a supply from the tanks, their depth was gauged, and the quantity evaporated the previous day was thus ascertained. The coke and cinders were then removed, the clinkers, if any, were separated, and the weight of each taken. The soot was cleared out at the end of the last day's experiment, and the total weight ascertained, which, divided by the number of trials, gave the average weight. Samples of the ashes, cinders and soot, were then put aside in bottles for the purpose of ascertaining the per centage of combustible matter present in the residue. The barometer was observed at about 11 o'clock in the day, being generally about 2 hours after the steam was up.

The method of estimating the quantity of combustible matter in the residue, was to heat the powdered substance in a stream of oxygen gas, by which the organic matter was dissipated chiefly as carbonic acid and water, and to estimate the loss as combustible matter.

Some difficulty was found in obtaining the mean temperature of the water in the boiler at the beginning and end of an experiment, arising from the normal level being established by letting down water to the bottom of the boiler by means of the pipe E′ E′ E′, and cold water being denser than hot, the cold water remained at the lower part of the boiler without mixing with that already contained in it, the two temperatures often varying as much as 70°, which would make a considerable difference between the real and apparent weight of the water contained

TABLE OF THE ECONOMIC VALUE OF COALS USED IN THE INQUIRY.

Names of Coals employed in the Experiments.	Economic evaporating power, or number of lbs of water evaporated from 212° by 1 lb of coal.	Weight of 1 cubic foot of the coal as used for fuel. lbs.	Weight of 1 cubic foot as calculated from the density. lbs.	Ratio of B to C, or of the economical to the theoretical weight.	Difference per cent. between theoretical and economical weights.	Space occupied by 1 ton in cubic feet (economic weight).	Results of experiments on cohesive power of coals: percentage of large coals.	Evaporating power of the coal after deducting for the combustible matter in the residue.	Weight of water evaporated from 212° by 1 cubic foot of coal.	Rate of evaporation, or number of lbs. of water evaporated per hour. Mean.
WELSH COALS.—	A	B	C	D	E	F	G	H	I	
Graigola	9·35	60 166	81·107	·712	34·8	37·23	49·3	9 66	581·20	441·48
Anthracite (Jones & Co.).	9·16	58·25	85·786	·679	47·26	38·45	68·5	9·7	565·02	409·37
Old Castle Fiery Vein .	8 91	50·916	80·42	·633	57·916	43 99	57·7	. .	455·18	464 30
Ward's Fiery Vein . .	9 40	57·433	83·85	·685	46·0	39·0	46 5	10 6	608·78	529·90
Binea	9 94	57·08	81·357	·702	42·53	39·24	51·2	10·3	587·92	486·95
Llangennech	8 86	56·93	81·85	·695	43·76	39·34	53 5	9·2	523·75	373·22
Pentrepoth	8 72	57·72	81·73	·705	40·17	38·80	46·5	8·98	518·32	381·50
Pentrefelin	6·36	66 166	84·726	·781	28·051	33·85	52·7	7·4	489·62	247·24
Duffryn	10·14	53 22	82·72	·643	55·43	42·09	56·2	11·80	540·12	409·32
Mynydd Newydd . . .	9 52	56·33	81·73	·689	45·09	39 76	53·7	10·59	536·26	470·69
Three-quarter Rock Vein	8·84	56·388	83·60	·674	48·26	39·72	52·7	. .	498·46	486·86
Cwm Frood Rock Vein .	8·70	55·277	78·299	·706	41·648	40·52	72·5	9·35	480·90	379·80
Cwm Nanty-gros . . .	8 12	56·0	79·859	·701	42·60	40 0	55·7	8 82	471·52	404·16
Resolven	9 53	58·66	82·354	·712	40 39	38·19	35·0	10·44	559·02	390·25
Pontypool	7·47	55·7	82·35	·676	47·845	40·216	57·5	8·04	416·07	250·40
Bedwas	9 79	50·5	82·6	·611	63·565	44·32	54·0	9 99	494·39	476·96
Ebbw Vale	10·21	53·3	78·81	·676	45·98	42·26	45 0	10·64	544·19	460·22
Porth mawr	7 53	53·3	86·722	·614	62·7	42·02	62·0	7·75	401·34	347·44
Coleshill	8 0	53·0	80·483	·658	51·85	42·26	62·0	8·34	424·0	406·41
SCOTCH COALS.—										
Dalkeath Jewel Seam . .	7·08	49·8	79·672	·625	59·984	44·98	85·7	7·10	352·58	355·18
,, Coronation Seam	7·71	51·66	78·611	·657	52·17	43·36	88·2	7·86	398·29	370·08
Wallsend Elgin . . .	8·16	51 6	78·611	·694	43·78	41·02	64·0	8·67	460·82	435·77
Fordel Splint	7·56	55·0	77·611	·699	42·92	40·72	63·0	7·69	415·80	464·98
Grangemouth , . . .	7·40	54·25	80·48	·674	48·35	40·13	69·7	7·91	401·45	380·40
ENGLISH COALS.—										
Broomhill	7·3	52·5	77·988	·673	48·55	42·67	65·7	7·66	383·25	397·78
Lydney (forest of Dean) .	8 52	54·444	80·046	·68	47·02	41·14	55·0	8·98	463·86	487·19
Slievardagh Irish Anthracite	9·85	62 5	99·57	·630	58·55	35·66	74·0	10·49	618·58	473·18
PATENT COALS.—										
Wylam's Patent Fuel . .	8·92	65·08	68·629	·948	5·45	34·41	. .	9 74	580·51	418·89
Bell's ,, ,, . .	8 53	65·3	71·124	·918	8·91	34·30	. .	8·65	557·0	549·11
Warlick's ,, ,, . .	10·36	69 05	72·248	·955	4 49	32·44	. .	10·60	715·35	457·84

in the boiler; and as this was one of the elements employed in calculating the evaporative value of the coals experimented on, it was thought important to be able to find the true mean temperature, which was done by means of a mixing apparatus consisting of a force pump P, by means of which water can be drawn from the bottom of the boiler, and passing in the direction of the arrows *a a a*, *b b b*, be distributed on the top by means of the perforated extremities of the tubes T T T. In another position of the three and four-way cocks R and S, the water passes directly from the tanks to the bottom of the boiler; while by a third modification in the position of the plugs of the cocks R and S, the water can be made to flow directly on the top of the boiler from the tanks E F, as shown by the arrows *c*, *b*. This mixing apparatus was used at the beginning and end of each experiment in the following manner:—Suppose an experiment to have been made the previous day, the first thing done in the morning was to turn the cocks R and S in a proper position, and then, by means of the pump P, force water from the bottom of the boiler on the top at T T T. This generally lasted ten minutes: when the cocks R and S being turned in another position, the normal level was restored by letting down water from the tanks in the direction of the arrows *c b*, when the cold water flowing from the apertures T, being denser than that contained in the boiler, falls to the bottom, and in doing so abstracts heat from the warm water through which it passes, until the equilibrium is restored; the temperature is then read off by means of the thermometer, and the cocks R and S are turned so as to allow water to flow directly to the bottom of the boiler in the direction *c*, in which position they remained during the whole of the experiment. The cocks T′ T′ T′ were shut to prevent the condensation of steam in the mixing apparatus, and also to cut off all communication with the boiler. In this way the temperature of the water in the boiler was made uniform, a difference of 2° being rarely observed between the thermometer L, and a thermometer placed in a stream of water allowed to flow from the cock X.[1] These operations were repeated every morning during the progress of the experiments, as also on that of the fourth day, when the series of experiments was completed. This last temperature is used in the calculations of the work done on the third day, whilst in the other cases the final temperature of one day is evidently the initial temperature of the succeeding.

Every sample of coal submitted to examination was accompanied by a certificate from the owner or his agent, and in the report a variety of particulars respecting the mine, the geological position of the coal, the method of working, the nearest port, the extent of trade, the physical character of the coal, &c.: and the results of the above experiments are added in a tabulated form. The following particulars respecting the Duffryn coal will show the mode of entry for all the coals examined:—

DUFFRYN COAL.

"I hereby certify that the casks of coal marked as in the margin of this certificate, contain a fair sample of the Duffryn steam coals, which were mined specially for the service of the 'Admiralty coals investigation.'—R. K. JONES, *Agent*."

The Duffryn steam coal is called the four-feet vein, and is obtained in the valley of Aberdare near Merthyr, in the county of Glamorgan. The depth of the pit is 288 feet, and the thickness of the vein is generally about 6 feet. It is worked in the form of stall and heading: the small and refuse is cast back or gobbed in the stalls and waste: the large coal is filled into waggons containing about a ton each, and conveyed from the stalls or heading to the top of the pit. The overlying stratum is strong clod or rock, and the subjacent stratum is strong fire-clay and rock. The dip of the vein is 1 in 9, or 4 inches in the yard, and crops towards the north. It is described as a free-burning coal, and its principal markets are London, Liverpool, Southampton, Dublin, and Plymouth. The distance from the colliery to Cardiff, the shipping port, is 22 miles, to which there is conveyance both by railroad and canal. No current price is given in the return, which states "that the coal has been shipped largely to the West Indies under contract with the government for steam purposes, and has also been sent to the Mediterranean and America, and has given much satisfaction."

This is a coal of rather a soft description, easily breaking up into small pieces with a bright appearance of fracture, but which is somewhat obscured by the apparent irregularity of its structure. It contains a considerable proportion of a white substance, but no iron pyrites were observed in it. Some portions of the coal, where the structure is well seen, show the lines of fibrous structure as perpendicular to the planes of deposition or bedding. Numerous very thin layers of a soft brownish substance are seen along the line of bedding.

Our remarks during the trials show that it kindles very readily and burns freely, raising the steam with great rapidity. It makes a remarkably clean fire, without any smoke, opening well on the bars without caking. No clinkers were made: the ashes and cinders left were clean, and of a whitish colour.

	December 1st day.	December 2d day.	December 3d day.
Fire lighted	8 h. 15 m.	8 h. 10 m.	8 h. 15 m.
Steam up	9 h.	9 h. 15 m.	9 h. 20 m.
Weight of wood used	10 lbs.	10 lbs.	10 lbs.
Initial temperature of water in boiler	206°	205°	206°
Temperature of water in tanks	42°	34°	38°
Barometer	—	—	—
Extremes of external thermometer	—	—	—
Extremes of internal thermometer	54—66°	48—62°	42—54°
Dew-point	—	—	—
Area of damper open	112 in.	112 in.	112 in.
Weight of coals consumed	337·5 lbs.	309·5 lbs.	321 lbs.
Weight of ashes left	8·5 lbs.	11·5 lbs.	16·5 lbs.
Per centage of combustible matter in ashes	52·76 lbs.	—	—
Weight of cinder left	8·5 lbs.	12·5 lbs.	12·5 lbs.
Per centage of combustible matter in cinder	89·74	—	—
Weight of clinker in cinder	None.	None.	None.
Average weight of soot in flues	1 lb.	1 lb.	1 lb.
Per centage of combustible matter in soot	51·39	—	—
Weight of water evaporated	2,876 lbs.	2,629 lbs.	2,793 lbs.
Weight of water evaporated from 212° by 1 lb. of coal	10·07 lbs.	10·07 lbs.	10·307 lbs.
Weight of coals per hour for 1 square foot of grate surface	8·43 lbs.	7·74 lbs.	8·01 lbs.
Duration of experiment	8 hours.	8 hours.	8 hours.
Specific gravity of coal	1·326	—	—
Mean weight of cubic foot of coal	53·22 lbs.	—	—
Economic weight or space occupied by one ton	42·09 cu. ft.	—	—
Cohesive power of coal	56·2	—	—

In reviewing this long and elaborate inquiry, the Commissioners state that the qualities which distinguish particular kinds of fuel are very varied, so that it is difficult to deduce general results. In the one economical application of coals, *viz.* their evaporative value, one variety of coal, which may be admirably adapted from its quick action for raising steam in a short period, may be far exceeded by another variety, inferior in this respect, but capable of converting a much larger quantity of water into steam, and therefore more valuable in the production of force. A coal uniting these two qualities in a high degree might still be useless for naval purposes, on account of its mechanical structure. If the cohesion of its particles be small, the effect of transport, or the attrition of one coal against another by the motion of a vessel, might so far pulverise it as materially to reduce its value. Even supposing the three qualities united, rapidity and duration of action with considerable resistance to breakage, there are other properties which should receive attention in the selection of a fuel, without the combination of which it might be useless for our steam navy. With respect to the bulk or space occupied by certain weights of different coals, two varieties of coals often equally good as regards their evaporative value, may differ as to the space occupied as much as 20 per cent.; that is, where 80 tons of one coal could be stowed, 100 tons of another of equal evaporative value might be placed by selecting it with attention to its mechanical structure.

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[1] This cock was used for blowing off the water, which was frequently done, in order to cleanse the boiler; for since the water contained on an average 20 grains of fixed matters per gallon, and from 300 to 400 gallons were daily evaporated, the boiler would otherwise have become rapidly coated with a residue which would interfere with and modify the experiments.

The various specimens of coals sent from different parts of the country were first analysed and examined in the laboratory, but as it was found that no practical result could be attained by this method alone, it was determined to test each variety of coal on a scale of sufficient magnitude to check the theoretical views by the practical results.

In ascertaining the true evaporative value of the fuel, several corrections were necessary before the final result could be arrived at. Some of these have been already noticed. Other circumstances also affect the evaporative powers of the coal, as for example, that all the water exposed to the action of the fire in the boiler is not converted into steam, and that wood is used to light the fire. The expansion or contraction of the boiler from an increase or diminution of the temperature, made a difference of nearly 70 lbs. of water in the contents of the boiler between the temperatures of 150° and 212°: allowance was therefore made for this even when the difference between the initial and final temperature was not greater than 10°. Other circumstances of less importance were neglected, such as the quantity of gases evolved during combustion, the elevation in temperature of the air entering the fireplace, the barometrical and hygrometric conditions of the atmosphere, the radiation from the boiler, (very small in amount, owing to its brick covering,) the hygrometric state of the fuel, or the heat necessary for obtaining mechanical draught in the chimney. With respect to the hygroscopic condition of the fuel, had wood been employed correction must have been made for it, but the hygroscopic nature of coal is very much less than that of wood. The latter contains $\frac{1}{5}$ of its own weight of hygroscopic water; and the heat necessary for the evaporation of this quantity might be shown by a simple calculation to be nearly equal to 22 per cent. of the total heat obtained by the combustion of the wood. The hygroscopic water in coal is however very small, as will be seen by the following determinations of some of the Welsh specimens experimented upon :—

	Hygroscopic water.
Graigola coal . . .	1·06 per cent.
Anthracite	2·44 ,,
Old Castle	0·74 ,,
Ward's Fiery Vein .	1·27 ,,
Myndd Newydd . .	0·67 ,,
Pentrepoth	0·78 ,,
Pentrefetin	0·70 ,,

Of the gases flying up the chimney, repeated analyses proved them not to contain any combustible constituent; the only products ever found being carbonic acid, sulphurous acid, oxygen, and nitrogen. The quantity of free oxygen in the chimney varied from $\frac{1}{4}$ to $\frac{1}{2}$ of the oxygen which combined with the fuel; in other words, nearly twice as much air passes through the fire as is strictly necessary by theory.

The heating values of coals depend on the quantity of oxygen required for their complete combustion. This may be estimated experimentally by heating the coal, with certain precautions, with an excess of litharge, or it may be determined by calculation from the known equivalents of the combustible ingredients of the coal. From the quantity of lead reduced by the coal, the oxygen employed in its combustion may be estimated, and the calorific values stand in direct relation to this quantity. The amount of oxygen necessary to consume the combustible constituents may be more accurately determined by elementary analysis; and thus calculated, the results are generally found to be about one-ninth greater than those indicated by experiment with the litharge. The calculation from the elementary analysis depends upon the circumstance that 6 parts or 1 equivalent of carbon require 16 parts or 2 equivalents of oxygen for combustion, while 1 part of hydrogen requires 8 parts of oxygen; it is only necessary, therefore, to subtract from the hydrogen a quantity corresponding to the oxygen contained in the coal, to enable the calculation to be made on these principles. As the calorific values are only relative, it is useful to refer them to the heating power of pure carbon, 1 part of which requires 2·666 parts of oxygen for combustion, and is capable, according to Despretz, of heating 78·15 parts of water from its freezing to its boiling point. The calculation may be simplified by multiplying each part of lead obtained by 2·265, which gives at once the weight of water capable of being heated between these temperatures by a unit of the coal used in reducing the litharge.

The economical values of coal are often influenced by circumstances which cannot be taken into account in chemical analyses. If, for example, the coal in the furnace should undergo destructive distillation before combustion commences, a large quantity of the constituents of the coal are rendered gaseous, and so much heat is expended in this act, that the heat developed by the subsequent combustion of these gases is frequently not greater than that abstracted during their formation. It would have been difficult to ascertain the proportion of fixed and volatile products in the various coals; this, however, was done in certain cases, of which a tabulated list is given, shewing the per centage of coke, tar, water, ammonia, carbonic acid, sulphuretted hydrogen, olefiant gas, and hydro-carbon, and other gases of an inflammable nature. Nor was it necessary to state the proportion of the fixed and volatile products, the per centage of coke being the chief point to be determined. [See the table in article COAL, p. 384.]

It has been supposed that the evaporative value of a bituminous coal may be expressed by the value of its coke, the heat of combustion of its volatile products being practically little more than is necessary to volatilise them. If this supposition were even near the truth, the most useful practical results might follow from it. By a larger and better applied system of gas manufacture, the volatile products of distillation might be made useful not only for the purposes of illumination, but also for domestic heat, and the residual coke might be used with an equal economy in our manufactures,[1] thus preventing the emission of that smoke which at present is so destructive to the comfort of our large cities. It is easy from analysis to examine whether the duty performed by the coal is to be attributed to its fixed ingredients, or coke, by estimating the work which the latter is capable of performing. This may be done by subtracting the amount of ashes in the coal from its amount of coke, and estimating the remainder as carbon. This carbon multiplied by its heating power, 13,268, and divided by 965·7, or the latent heat of steam, indicates the number of pounds of water which the coke by itself could evaporate without the aid of the combustible volatile ingredients of the coal.

The whole system of manufacturing coke is at present very imperfect. Besides losing the volatile combustible substances, which under new adjustments might be made of much value, an immense quantity of ammonia is lost by being thrown into the atmosphere. Ammonia and its salts are daily becoming more valuable in agriculture, and it is their comparative high price alone which prevents their general use in all kinds of cereal cultivation. By a construction of the most simple kind, the coke ovens now in use might be made to economise much of the nitrogen which invariably escapes in the form of ammonia. The price of sulphate of ammonia is about 13*l.* per ton, and in coking 100 tons of coal about six tons of this salt may be produced.

By the data furnished by this report, the actual value of the coals may be contrasted with that which is theoretically possible, supposing their combustion to proceed under circumstances which prevented any loss of heat. The actual duty obtained by a pound of coal from the boiler employed may be easily expressed by the number of pounds raised to the height of one foot. This result may be readily obtained by the simple formula—

$$W \eta \times 965{\cdot}7 \times 782 = x.$$

W representing water, of which η pounds are evaporated by a pound of coal. This formula is deduced from the fact that η pounds of water multiplied by 965·7, or the co-efficient for the latent heat of steam at 212°, indicates the number of pounds of water which would be raised 1° Fahr.; and the number 782 arises from experiment on the mechanical force denoted by the elevation of a pound of water 1° Fahr.; that force being equal to 782 pounds raised to the height of 1 foot, according to the careful experiments of Mr. Joule on the friction of oil, water, and mercury.

The best Cornish engines are said to be capable of raising 1,000,000 pounds to the height of one foot for every pound of coal consumed; this is only about [illegible]th of the actual force generated, or only [illegible] or [illegible] of the theoretical force. The various experiments made on boilers with regard to the evaporative power of coal have not given uniform results. Smeaton in 1772, with one pound of Newcastle coal, evaporated 7·88 lbs. of water from 212°; Watt, in 1788, fixed the quantity at 8·62 lbs.; Wicksteed, in 1840, found that 1 lb. of Merthyr coal could be made to evaporate 9·493 lbs. of water from 80°, which is equal to 10·746 lbs. from 212°. In some experiments made on the boiler of the Loam's engine at the United Mines in Cornwall, each pound of coal was found by a trial of six months to evaporate 10[illegible] lbs. of water from 212°. It has been stated that 1[illegible] lbs. of water have been evaporated by 1 lb. of coal burned in Cornish boilers, but as this is the utmost quantity theoretically possible, the statement requires to be reconsidered. According to some experiments undertaken in Cornwall, at the request of the commissioners, it was found that 11·42 lbs. of water were evaporated by every lb. of Welsh coal corresponding in composition to that of Mynydd Newydd.

With regard to the patent fuels, although their specific gravity is lower than that of ordinary coals, yet from their brick-like shape and mechanical structure they generally occupy less space than an equal weight of coals. Many of the patent fuels, however, are made up of the dust of bituminous coal, cemented together with bituminous or tarry matter. They would more nearly resemble the best coals by mixing a more anthracitic coal with the tar. But according to the practice indicated, it would be almost impossible to prevent the emission of dense opaque smoke. Besides this, the very bituminous varieties are not well suited to hot climates, and are as liable to spontaneous combustion as certain kinds of coal. To avoid these inconveniences some kinds of patent fuel are subjected to a sort of coking.

It is important to obtain exact information respecting the effects likely to be produced on coals by stowage and continued exposure to high temperature. The coals may not only deteriorate under such circumstances, but emit inflammable gases,

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(1) In this case it would be necessary not to carry on the process of distillation so far as at present, as the residual coke would be more combustible and the gases purer.

and produce dangerous explosions. Coal at ordinary temperatures evolves carbonic acid and nitrogen, together with inflammable gases, showing that a slow combustion or decay is going on in consequence of exposure to the oxygen of the atmosphere. This change in coal takes place more rapidly at an elevated temperature, as in hot climates, and it is also greatly favoured by moisture. When sulphur or iron pyrites is present in considerable quantity in a coal still changing under the action of the atmosphere, a second powerful heating cause is introduced, and the coals may spontaneously take fire. The best method of prevention is to dry the coals thoroughly before they are stowed away, and to select a variety of fuel not liable to the progressive decomposition above alluded to.

If the coal be kept in iron bunkers and be liable to be wetted with sea-water, the iron will become speedily corroded, in consequence, apparently, of the carbon or coal forming with the iron a voltaic couple, and thus promoting oxidation. The action is similar to that of the tubercular concretions on the inside of iron water-pipes when a piece of carbon not chemically combined with the metal and in contact with saline waters produces a speedy corrosion. A mechanical protection is sometimes sufficient, such as a coat of Roman cement, a lining of wood, or drying oil, driven into the pores of the iron with great pressure.

FULCRUM. See LEVER.

FULLER'S EARTH, a kind of lithomarge clay of a greenish or yellowish grey colour; it is soft and friable, coarse or fine grained, with a greasy feel; its sp. gr. varies from 1·8 to 2·2. It forms a non-plastic paste with water. Its constituents are, according to Dr. Thomson's analysis, silica 44 per cent., alumina 23·06, lime 4·08, magnesia 2, peroxide of iron 2, water 24·95. Hence, supposing the lime, magnesia, and iron to be in the state of silicates, as accidental ingredients, fuller's earth is a hydrous bisilicate of alumina, and two equivalents of water. It was formerly much used in the cleansing of woollen cloth in the operation of *fulling*, whence the name; its cleansing action depending on the affinity of its alumina for greasy matters. The fullers generally use it before they apply soap. Fuller's earth is found in several parts of England, but chiefly in Surrey, Kent, Bedfordshire, Hampshire, Bath, Nottinghamshire, and Sussex. At Nutfield, near Reigate, in Surrey, it occurs in regular beds, near the summit of a hill, between beds of sand or sand-stone, containing fossil wood, cornua ammonis, &c. There are two distinct beds of fuller's earth; the upper is of a greenish colour, and is 5 feet in thickness; this rests upon the other bed, which has a bluish tint, and is 11 feet in thickness. Masses of sulphate of barytes, often in regular crystals, are found in these beds, particularly in the latter.

The earth is prepared by baking, or, where fuel is scarce, by heating in the sun; it is then thrown into cold water, when it falls into powder. The separation of the fine from the coarse powder is effected by the simple but beautiful operation of *washing over* (as described under EMERY, p. 594), three or four tubs being used for the purpose. The different kinds of earth thus obtained are used for cleansing fine or coarse cloth.

FULLING. See HAT—WOOL.

FULMINATING POWDER. This may be prepared in various ways; as for example:—a mixture of 3 parts nitre, 2 of dry carbonate of potash, and 1 of sulphur, forms a fulminating powder, a small portion of which placed on a metal plate, and heated to about 330° will blacken, fuse, and explode with violence in consequence of the rapid action of the sulphur upon the nitre, and the sudden evolution of nitrogen and carbonic acid, the residue being chiefly sulphate of potash. The fulminating powder used in percussion caps is prepared from MERCURY, and will be described under that head. Fulminating powders from GOLD, SILVER, and PLATINUM will be noticed in the articles on those metals.

FULMINIC ACID. An acid existing in certain fulminating compounds: it has not yet been isolated: it will be noticed in the description of the process for preparing fulminating powder under the article MERCURY.

FUMIGATION is an application of vapours or fumes for the purpose of getting rid of unpleasant or unwholesome smells. By the old method, vapour of hot vinegar, aromatic pastiles, and vegetable matters, the smoke of burning brown paper, burnt feathers, tobacco, &c. were supposed to be effectual; and one or other of these substances is still occasionally employed; but in all these applications little more is done than to substitute one bad smell for another, by overpowering, not displacing or destroying the bad or dangerous odour; and in the case of tobacco, its reputed purifying and antiseptic properties furnish an excellent excuse to those who have the misfortune to smoke, of rendering the house always unpleasant, and not at all more free from infection. The only efficacious kinds of fumigation are by means of gases which decompose the miasmata or fumes, and convert them into innocuous compounds: such gases are sulphurous acid, muriatic acid, nitrous acid, and chlorine; the last named, either in its free state or in combination with lime, or soda, being incomparably the most convenient, efficacious, and powerful. [See CHLORINE.]

Sulphurous, and the other gaseous acids, are supposed to perform, indirectly, important service in maintaining a large city like London in a healthy condition. The products of the combustion of coal may operate in checking the spread of malignant diseases; the manufactories of chloride of lime and other chemical works may also be of use, although the benefit derived from them is seriously counteracted by trades which deal largely in the conversion of refuse animal matters; and were it not for the sewerage of London (imperfect though it be) and the water companies, the effects of our large consumption of animal food, and the presence of slaughter-houses in every parish, would be more severely felt. In times of plague and other pestilence the vicinity of smelting furnaces was formerly resorted to as being least liable to infection, the sulphurous and other acid fumes acting as disinfectants.

The theory of infection and contagion is very imperfect, and therefore the mode of action of disinfectants must be equally so. We are ignorant of the influence and production of malaria, of marsh miasma, and other poisonous exhalations of organic, but chiefly of vegetable, origin, which produce that extraordinary disease the ague, or intermittent fever. One of the most remarkable properties of some forms of infectious matter is its permanency, retaining, as it frequently does, its peculiar powers for a long, if not for an indefinite, period. Of this, the preservation and transmission of dried variolous and vaccine matter is a familiar example. Professor Brande states, that "the infection of scarlet fever is sometimes retained for weeks and months by articles of wearing apparel; in one instance, after a malignant form of that disease had prevailed in a house, it was fumigated with chlorine and whitewashed, and every article of furniture and clothing cleansed and fumigated, with the exception of a handkerchief, which had been accidentally overlooked, and to which the appearance of the disease, after a period of two months, was probably attributable. Blankets and woollen goods seem especially retentive of such poisons, and in all doubtful cases should be burned."

In 1825 Dr. Faraday was employed to fumigate the Penitentiary at Millbank, London. The space requiring fumigation amounted to nearly 2,000,000 cubic feet, and the surface of the walls, floors, ceilings, &c., was about 1,200,000 square feet. This surface was principally stone and brick, most of which had been lime-washed. The fumigation was performed by means of chlorine generated in the following manner. A quantity of salt in powder was mixed with an equal weight of black oxide of manganese, and upon this mixture was poured a cold solution of 2 parts of sulphuric acid and 1 part water. The acid and water were mixed in a wooden tub, the water being first put in, and it being more convenient to measure than to weigh the water and acid, 10 measures of water and 9 of acid were used: half the acid was added first, the remainder being added when the mixture was cold. $3\frac{1}{2}$ lbs. of the mixture of salt and manganese were put into a common red earthen pan, of the capacity of about a gallon, to which a measure equal to $4\frac{1}{2}$ lbs of the dilute acid was added: the mixture was then well stirred and left to itself. A number of these pans, each containing a similar dose, being thus arranged, all the apertures were closed, and as the action did not commence immediately, the operator could pass from pan to pan without inconvenience from the suffocating fumes of chlorine. On entering a gallery 150 feet in length, a few minutes after the mixture had been made, the general diffusion of chlorine was evident; in half an hour it was often almost impossible to enter, and frequently, on looking along the gallery, the yellowish green tint of the gaseous atmosphere could be perceived. Up to the fifth day the colour of the chlorine could generally be observed in the building: after the sixth day the pans were removed, though sometimes with difficulty, and the gallery thus fumigated had its windows and doors thrown open. The charge contained in each pan was estimated to yield about $5\frac{1}{2}$ cubic feet of chlorine: in fumigating the space of 2,000,000 cubic feet, about 700 lbs. of common salt and the same of black oxide of manganese were employed, yielding about 1,710 cubic feet employed to disinfect this space. In ordinary cases Dr. Faraday conceives that from $\frac{1}{2}$ to $\frac{1}{4}$ this quantity of chlorine would suffice.

FUNNEL, a hollow conical vessel, with a small pipe issuing from its apex, used for conveying fluids into vessels of small apertures: it is also of use in filtering. [See FILTRATION.] For domestic purposes funnels may be made of copper, pewter, or tin-plate; but in the laboratory no funnel made of a material likely to be corroded by acids or alkalies should be allowed: the funnels should be of glass, earthen, or stoneware.

FUR, a material for warm clothing, largely required by the inhabitants of cold countries, where it is also most richly supplied; for it consists of the skins of such animals as are covered for their own protection with thick, soft hair; and the colder the country, the more abundant the provision thus made for them. The skins taken from these animals, when properly prepared on the inner side, are extremely durable, often very beautiful, and form the most comfortable description of clothing which can be worn in severe climates. In the prepared state, the skins are called fur; but without any preparation, they go by the commercial name of *peltry*.

The extensive and almost universal employment of fur as an article of dress, during our own comparatively mild winters, will give some idea of the demand for this material in less favoured climates. In Russia, Poland, East Prussia, Hungary, Bohemia, Saxony, &c., lambs' skins constitute an essential part of the dress of thousands among the lower classes, and the skins of various other animals may also be considered as articles of absolute necessity. The principal consumption of the more beautiful and costly furs, which rank as articles of fashion and luxury, is in China, Turkey, Russia, and England.

So early as the sixth century, the skins of sables formed an article of fashionable attire at Rome, and were brought from the confines of the Arctic Ocean, at great cost, to supply the demand of that wealthy capital. Several centuries elapsed, however, before Western Europe sought after a similar luxury. The traders of Italy brought a considerable supply to England in the time of Edward III.; so much so, that the monarch thought fit to prohibit their use, except among the wealthier classes.

The Canadian fur trade was commenced by the French, soon after their settlement on the St. Lawrence, and was at first extremely profitable, because the Indians, unconscious of the worth of the skins, would readily exchange them for beads, nails, hatchets, trinkets, and other articles of inadequate value. At first there was also an almost unlimited supply; but when the hunting-grounds in the neighbourhood of the European settlements became exhausted, longer journeys were necessary, and various settlers, under the name of *coureurs des bois*, or wood-rangers, made excursions to more distant hunting-grounds, sometimes remaining there for many months, adopting the habits of the Indians, and forming connexions with them. But the measure of success attending this branch of traffic soon brought other speculators into the field. A company was formed in London, and chartered by Charles II. in 1670, for the purpose of trading in fur with the Indians inhabiting the region to the north and west of Hudson's Bay, and hence called the Hudson's Bay Company. This association became prosperous, founded many establishments, and carried on its trade with success for more than a century. It then met with a powerful competitor in a new company, consisting of wealthy and influential British settlers in Canada, and others, who recognised no exclusive right in the Hudson's Bay Company to trade in a particular region; the charter granted to them never having been confirmed by Act of Parliament. This second company (called the North-west Company) carried on its affairs with great spirit and energy, having its chief establishment at Montreal, but trading upwards of four thousand miles further to the north-west. Where these companies came in contact, animosities arose, which occasionally led to the commission of actual violence between the servants of each. After a long course of dissention, the two companies at length united into one powerful body, under the name of the Hudson's Bay Fur Company, which now engrosses the principal part of the fur trade of British America. The Indian trade of the great lakes and the Upper Mississippi is principally enjoyed by the North American Fur Company, whose chief establishment is in New York. But we are told that, with the exception of the musk-rat, most of the fur-bearing animals are exterminated in the vicinity of the lakes.

A large supply of furs is, therefore, received through the Hudson's Bay Company, whose immense hunting-grounds afford a varied and almost endless amount of valuable skins, and whose possessions, or the lands over which they claim control, extend to nearly one-eighth of the habitable globe. The great fur-sales of this company are held in London every year, during the month of March, and attract great numbers of foreigners. Through their means the greater part of the furs destined for the Continent find their way to the great fair at Leipsic, whence they are distributed throughout Europe. In former days, the beaver was one of the most valuable furs of this company; but it is of far less importance at the present time, because the principal use to which it was applied, in the manufacture of hats, is now greatly diminished. But by a new process, and by the application of an ingenious machine, the skin of the beaver is now cut, and converted into a handsome fur for ladies' use. There has also been a successful attempt to employ its fine silky wool for weaving purposes. The skin of the black and silver fox is highly prized in the Russian and Chinese markets, and is the most valuable of that family; but the red fox is also used by the Chinese, Persians, Greeks, &c., as linings and trimmings for robes, which are ornamented in spots or waves with the black fur of the paws of the same animal. The white and blue fox is also used for ladies' wear. The finest raccoon furs are also the produce of North America. They are extensively used in Russia and throughout Germany, as a lining for gentlemen's coats, the darkest skins being preferred.

The Hudson's Bay martin, or sable, is a valuable and useful fur, and is used in large quantities in this country, and in France and Germany. So is also the mink, which is exclusively the produce of that company's possessions and of North America. The fur of the wolf is also used in cold countries for cloak-linings, coverings of sleighs, &c. The soft, warm, and light fur of the lynx is also in much request for linings, &c. In its natural state it is greyish-white, with dark spots; but to prepare it for certain markets it is dyed of a beautiful glistening black. The heavy fur of the sea-otter is of great commercial value, and is said to be the royal fur of China. It is worn by officers of state, mandarins, and other important persons: it is also held in great esteem in Russia for facings, trimmings, collars, &c. of gentlemen's dresses; but it is unfit for ladies' wear, on account of its great weight. The fur of the North American black bear is valued for military purposes at home and abroad. It is formed into caps, rugs, pistol-holders, hammercloths, sleigh-coverings, &c. The fur of the brown bear is used by American ladies. The musquash, or musk-rat, is also imported into this country in great numbers. It was formerly used in the hat manufacture, but now, with some preparation, is converted to the ordinary purposes of fur. The Hudson's Bay otters are chiefly procured for Russia and Greece, where they are used for caps, collars, &c.

Important as is the trade thus carried on with the New World for the furs of her northern countries, yet there are some furs, and those the most costly, and highly esteemed among ourselves, for which we are indebted to Northern Europe and Asia, the great trade in them being carried on by Russia. The ermine is one of these, a fur which is produced in many countries, but only in perfection in Russia, Sweden, and Norway. The animal producing it is the stoat or weasel of southern climates, but its peculiar value, in this instance, arises from a provision of nature, by which the animal becomes pure white in winter, in those snow-covered regions, where it would otherwise be exposed more clearly to the view of its enemies.[1] The ermine, therefore, must be sought and killed in winter, to produce the celebrated fur, which is the royal fur of England, as it is also of Russia, Germany, Spain, Portugal, &c. The tail, alone, of the animal is jet black at the tip, and this, in ordinary wear, is inserted at intervals in the fur, as an ornament. There is no restriction on the wearing of this fur in England at the present day, but in the reign of Edward III. it was expressly forbidden to all but the royal family (a similar prohibition still exists in Austria). There is, however, a distinction made in the mode of ornamenting the fur as employed on state occasions, according as it is to be worn by the sovereign, or by peers, peeresses, judges, &c. The sovereign, and members of the royal family can alone wear ermine trimmings to their robes of state, in which the fur is spotted all over with black—a spot in about every square inch of the fur. These spots are not formed of the tail of the ermine, but of the paws of the black Astracan lamb. Peeresses wear capes of ermine, in which the spots are arranged in rows, the number of rows denoting their degrees of rank. Peers wear robes of scarlet cloth trimmed with pure white ermine, without any spots. But the number of rows or bars of pure ermine in this case, also denotes the rank. The robes of judges are also scarlet and pure white ermine. In heraldic language, this fur is called *minever*.

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[1] The effect of cold on the fur of the Hudson's Bay Lemming was made the subject of an experiment during Ross's voyage. The little creature was kept in a cage during several months in the warm cabin, during which time it retained its summer fur. It was then determined to try the cruel experiment of exposing it on deck, at night, to a temperature of 30° below zero. After one night's exposure, the fur on the cheeks, and a patch on each

The ermine is a small animal, the extent of the skin, exclusive of the head and tail, not being above ten or twelve inches. The best fur is furnished by the oldest animals, which are taken either in snares and traps, or by shooting at with blunt arrows. The skins are always sold in lots of forty, called the timber.

Next in value and general use are Russian sables, the best of which are extremely costly and beautiful.

These are used for civic robes, &c., as the ermine is for court and parliamentary dresses. The lining of a robe of state, if made of the finest sables, may be worth a thousand guineas. Skins of the best quality are procured by the Samoieds, and in Yakutsk, Kamschatka, and Russian Lapland. The length of the animal (which by some naturalists is considered to be a variety of the pine-marten) is from eighteen to twenty inches. The darkest in colour are considered the most valuable. The produce of Russia in these costly and beautiful skins, is about twenty-five thousand annually. The tails of sables are used in the manufacture of artists' pencils or brushes. A great quantity of mink-sable, which, as we have said, is exclusively the produce of the Hudson's Bay Company's possessions, is sold to the inexperienced as real Russian sable. There is an inferior sable called Kolinski or Tartar sable, which is procured from Russia. The animal belongs to the weasel tribe, and is of a bright yellow colour. This fur, when dyed, is sold among the cheaper sables, but it is also much used in its natural state.

The fur of the squirrel is exported from Russia in immense and almost incredible quantities, the produce of that country being estimated at about twenty-three millions of skins annually. This country alone received from thence, during the year 1850, upwards of two million skins. The back of the grey squirrel is most in request, but the white portions, from the belly of the same animal, are also largely used for linings, &c. The favourite Weisenfels cloak-lining is made from the white part of the dark blue squirrel, and is so extremely light, that the lining for a full-sized cloak does not weigh more than 25 ounces. It is known as the *petit gris*. The lamb-skins of Russia are celebrated, especially the skin of the Astracan lamb, which is fine, rich, and glossy like silk, and is said to be obtained from the immature animal, the parent sheep being destroyed to obtain it. Of the Persian grey and black lamb it is also averred, that the animal is sewn up tightly in leather as soon as it is born, that the small curls which cover the skin may not expand. The national dress of Hungary is made of the lambs'-skins of that country, worn in summer with the fur outside, in winter the reverse. The skin is tanned in a peculiar way, and ornamented according to the fancy of the wearer. The short jacket worn by Spaniards, is of lambs'-skin, decorated with filligree silver buttons.

The skins of hares and rabbits are used in common with beaver and nutria (or coypou) skins for felting purposes; they are also dressed and dyed for conversion to various other uses. Rabbits' fur is made into a cloth for ladies' use; the skins of the finer sorts of rabbit are much employed for linings, &c., the skin of the white Polish rabbits forming no mean substitute for ermine. The silver-grey rabbit formerly peculiar to Lincolnshire, but now bred in warrens in other parts of the country, is invariably exported to China and Russia, where it is in great demand, and secures a high price. It has been remarked as a peculiar feature of the fur-trade, that almost every country or city which produces and exports furs, imports and consumes the fur of some other place frequently the most distant. An article is seldom consumed in the country where it is produced, but is eagerly sought after in another quarter of the globe. A suit of English silver-grey rabbit is rarely seen here, and when exhibited, is far from securing the admiration which it meets with in China.

Other skins in less general use are the chinchilla, introduced about fifty years since from South America, where it is exclusively found; the fur seal, divested of its long coarse hair, and retaining the curly, silky, yellow down, which when dyed of a rich brown colour, supplies a fur of velvet-like softness; the tiger, used to cover seats of justice in China, and also employed for rugs, &c.; the leopard, worn as a mantle by the Hungarian nobles who form the royal

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shoulder, had become perfectly white. On the second day, those patches had extended, and the posterior part of the body and flanks had turned to a dirty white. During the next four days, the changes continued, and at the end of a week, the animal was entirely white, with the exception of a dark band across the shoulders. The animal at length died from the severity of the cold, and on examining the skin, it appeared that all the white parts of the fur were longer than the uncoloured portion, and that the ends of the fur only were white so far as they exceeded in length the dark-coloured fur, and by removing these white tips with a pair of scissors, it again appeared in its dark summer dress.

body-guard; used also as an officer's saddle-cloth by some of our own cavalry regiments; the Angora goat, whose long silky coat once formed a costly article of ladies' wear, but is now of small value, and is chiefly used for carriage and drawing-room mats and rugs; buffalo skins, which have been of late years much used in Europe as robes and wrappers in severe climates; the cat, which, when bred for the purpose, as it is largely in Holland, supplies a useful and very durable fur.

Substitutes for fur have been found in the plumage of birds; thus swan's-down, goose-down, egret-down, and the silvery plumage of the grebe, are convertible to ladies' use. The down from the bird called the egret is so rare and costly that only a few sets have been made during a century, one of the last having been fabricated in Paris for the Great Exhibition of 1851.

The dressing or preparing of furs for use, is a very simple operation when the furs are to remain on the original felt, and to be worn as garments, trimmings, &c. In early times, the skins were worn nearly in the state in which they were taken from the animals, but as the wearing of fur gradually became a matter of fashion, instead of a mere matter of convenience or necessity, so the preparation of it was more carefully attended to. The first process belongs to the hunter, who, on capturing a fur-bearing animal, strips off the skin, and hangs it up to dry in the open air, or in a cool room without a fire. If the skin be well dried, and carefully packed, it reaches its destination, however distant, in excellent condition; but if any moisture be left, or if it be packed with skins less carefully dried, so that the slightest degree of putrefaction takes place, then the fur is unfit for use, so far as the furrier is concerned. A minute examination of the skins is therefore his first business; after which, his next care is to cleanse them from greasiness, by steeping the skins in a liquid containing bran, alum, and salt, and then working and scouring them in the same. But this process does not entirely remove a kind of oil which is found in the fur itself. This is removed by an application of soda and soap. Finally, the skin is washed in clear water and dried, the previous treatment having effected a kind of tanning process, and converted it into thin leather, adapted to be cut up into articles of dress. The cutting up of the skins requires some judgment, to avoid waste. It is well known, that the fur of an animal is scarcely ever of the same colour all over the surface, the back usually presenting the darkest and richest colour, and the under parts a much lighter hue. In cutting out material for muffs, mantles, &c., the same harmonious colour is required throughout, therefore the best portions of several skins, corresponding in quality and colour, must be selected, and the rest refused. But this refuse, if not cut to waste, is equally available for making articles of a less costly description, and the skill in joining these pieces, even to the smallest portion, so that they shall appear as one skin, is not a little remarkable. Many a lady, on having her furs fresh lined under her own superintendence, has viewed, with surprise approaching to dismay, the elaborate patch-work which the skins present on their inner side.

Skins that are to be used in felting, as hare, rabbit, beaver, nutria skins, &c., undergo a longer process. Hares' fur is first cleaned on the outside with a tool called a rake, then damped on the inside, and several pressed together to remove creases. Next, the longer portion of the hair, which has no felting property, is carefully sheared off without injuring the soft thick fur beneath. The skin is then stretched out on a cutting-board made of willow, and kept damp. A knife about six inches long by three broad is then applied in the direction the fur naturally lies, and gradually removes it from the pelt in a light fleecy mass. In preparing rabbit-skin, the long hair is pulled out by a short knife, the thumb of the operator being protected by a leather shield. The skin also requires careful cleaning, on account of its greater greasiness. The inner cuticle is stripped off, and the surface beneath it rubbed with whitening.

A somewhat similar process is adopted with beavers' skins, which are so full of grease, that nothing but a thorough scouring with fuller's earth and whitening will bring them into condition. In these also the long hairs are removed by pulling out; the under fur, however, is not removed by hand. A machine has been contrived, by which a broad and sharp blade, of the full width of the skin, falls rapidly, and with a chopping action, near the edge of another blade beneath. The skin is fastened to a part of the machine which draws it between the blades from end to end, and as it passes along, the fur is completely cropped from the pelt without any injury to the latter. Falling on an endless apron, the fur is removed, and transferred to a large chest, where it is powerfully acted on by a fan, which revolves two thousand times in a minute, carrying the fur along a hollow cylinder or channel fifty feet long. As it passes, the fur becomes separated into different qualities, simply by its own specific gravity. The largest and coarsest hairs fall first, the next further on, and so on, the finest being carried to the extreme end. The pelt of the beaver is very smooth and uniform, therefore the fur can be conveniently removed by the above machine; but for other and less regular skins, it is found inapplicable. Nutria skins are subjected to thorough washing and purification with soap and boiling water, being full of fat and oily matter. These skins resemble, in some degree, those of the otter; and in fact, the name commercially given to them is derived from the Spanish word for "otter." Several other kinds of fur have been turned to felting purposes with inferior effect, such as the fur of the mole, musk-rat, seal, and otter. The felting property can be increased by wetting the skin on the inner side with dilute sulphuric acid, while yet the fur remains upon it, and then quickly drying it near the fire, or by passing a hot iron over it. This process is called *carrotting*, from the colour it imparts to the fur. [See APPENDIX.]

FURNACE, (Latin, *fornax*,) an enclosed fire, differing from the common grate in the mode by which the draught is supplied: for while in the common grate the air rushes in through the front as well as the bottom bars, it is supplied in the furnace at the bottom only, and that with considerably increased velocity compared with the common grate.

Numerous forms of furnace are employed in the Useful Arts: some of them have already been described; others will be noticed hereafter. In the laboratory "there is scarcely any limit," as Dr. Faraday remarks, "to the number of furnaces that have been contrived as particularly adapted either for special or general uses; all, no doubt, were good at the time they were devised, and superior, for some reason or other, to those which had preceded them; but the character of chemical operations has changed so much as to render many of these contrivances useless, or of little importance, and each person is now left to select those which are most agreeable to himself, as according best with either his notions or modes of experimenting." The general working furnace of the laboratory is thus described by the same excellent authority:—"Its use is partly domestic, partly chemical; for it has to warm and air the place occasionally, to heat water, as well as to supply the means of raising a crucible to ignition, or of affording a high temperature to flasks through the agency of a sand-bath. These objects are best obtained by those furnaces which are built with a table-top. The fire-place itself is constructed of brick-work with iron front and fittings, and the flue being conveyed horizontally for 3 or 4 feet, is afterwards carried off to, and connected with, the main flue existing in the wall. The fire-place and horizontal flue are covered with a large plate of cast-iron of from 2 to 3 feet in width: this is formed in the middle, over the heated part, into sand-baths, a round movable one over the fire itself, and a long fixed one over the flue. The sand-baths supply every gradation of heat, from dull redness, if required, down to a temperature of 100°, or lower; whilst on each side of them exists a level surface which answers every purpose of an ordinary table, and supplies extraordinary facilities to experiments going on in the sand-bath or furnace. Nor are these advantages gained by any serious sacrifice of heating power in the furnace itself, for it is easy so to construct it as to make its ordinary combustion not more rapid than that of a common fire, and yet, by closing the fire-door and opening the ash-pit, to obtain a heat that will readily melt gold, silver, or cast-iron."[1]

The above description of furnace is properly a *wind-furnace,* in which the temperature required for all the purposes to which it is applied, is obtained without the use of bellows, by means of a powerful draught, dependent on a narrow flue or chimney of considerable elevation. Fig. 1015 will give some idea of the small wind-furnace used by refiners and those who melt metal in pots. This furnace is shown connected with and projecting from the chimney: it should be of such a height as to allow the operator to look in to it on raising the cover or trap-door: it should be 12 or 15 inches square, and be furnished with movable bars: every part exposed to the fire should be formed of the most refractory bricks. When a very strong heat is required, the air should be conveyed by pipes from the exterior to the ash-pit. In the figure, a crucible is shown as placed in the furnace: the fuel used is coke, or a mixture of coke and charcoal.

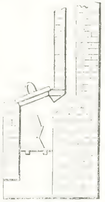
Fig 1015.

The small *blast-furnace* represented in Fig. 1016 is described by Dr. Faraday from the one in the laboratory of the Royal Institution. The exterior consists of a blue pot, 18 inches high, and 13 inches in external diameter at the top. A small blue pot, $7\frac{1}{2}$ inches internal diameter, had the lower part cut off, so as to leave an aperture of 5 inches. This, when put into the larger pot, rested upon its lower external edge, the tops of the two being level. The interval between them, which gradually increased from the lower to the upper part, was filled with powdered glass-blowers' pots, moistened with water, and pressed down into a compact mass. A round grate was then dropped into the furnace, of such a size that it rested an inch above the lower edge of the inner pot: the space beneath it, therefore, formed the air-chamber, and the part above it the body of the furnace. The former is $7\frac{1}{2}$ inches from the grate to the bottom, and the latter $7\frac{1}{2}$ inches from the grate to the top. A horizontal conical hole, $1\frac{1}{2}$ inch in diameter on the exterior, was cut through the outer pot, forming an opening into the air-chamber at the lower part, for the purpose of receiving the nozzle of a pair of double bellows. The furnace must be perfectly dry before being used. The fuel is coke. The bellows are mounted on an iron frame, and the furnace is raised upon an iron stool, so as to bring the aperture of the air-chamber to a level with the nozzle of the bellows. This furnace is sufficiently powerful to melt pure iron in a crucible in twelve or fifteen minutes, the fire having been previously lighted. It will effect the fusion of rhodium, and even pieces of pure platinum have sunk together into one button in a crucible heated by it. All kinds of crucibles, including the Cornish and the Hessian, soften, fuse, and become frothy in it. Such a furnace as this should be used in the open air.

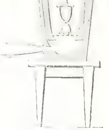
Fig. 1016.

The *blast-furnace* used in making pig iron will be described under IRON: for the *reverberatory* furnace, see COPPER, and some other articles relating to metallurgy: for the *assay* or *cupelling* furnace, see ASSAYING. See also APPENDIX for Gas-furnace.

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[1] Chemical Manipulation, Sect. I.

FUSEE. See Horology.

FUSIBILITY. See Heat—Metals.

FUSIBLE METAL. See Alloy—Bismuth.

FUSTIAN, a coarse, thick, tweeled cotton, similar in the mode of manufacture to velvet, and generally dyed of an olive, leaden, or other dark colour. Besides common fustian, (known as *pillow* or *pillaw*) *corduroy*, *velverett*, *velveteen*, and *thicksett*, used for men's apparel, belong to the same class of fabrics. See Weaving.

FUSTIC, a dye-stuff, the *bois-jaune* of the French, is the wood of the *Morus tinctoria*, a large tree growing in Brazil, Jamaica, and most of the West Indian islands. A concentrated decoction of fustic, deposits, on cooling, a yellow crystalline matter named *morine*. 1 part of fustic boiled in 10 of water for 15 minutes, gives a yellow decoction, which gradually deposits morine. The decoction is inodorous, slightly astringent and bitter, and precipitates gelatine. With protochloride of tin, and with alum, it gives yellow precipitates; orange-coloured with acetate of lead; yellow-brown with acetate of copper, and dark olive with persulphate of iron. With sulphuric acid, it gives an orange-coloured precipitate, soluble in excess of the acid. It is reddened by nitric acid, and rendered paler by oxalic and by acetic acid. The yellow of fustic is said to produce several greens with indigo, with which it unites well.

Fustic is admitted into the United Kingdom free of duty.

FUZE. See Mine—Quarry.

GAGE, or GAUGE, an apparatus for measuring the state of a phenomenon; as the *air-pump gage*, which points out the degree of exhaustion in the receiver, [see Air, p. 29,] the *wind-gage*, [see Anemometer,] &c. There are also various gages used in particular trades and manufactures, such as those for measuring wires and sheet metals: these are usually thick plates of steel, of several sizes and forms, around and near the edges of which are drilled various holes, with notches sawed from the edge into every hole, saws of the widths of the several notches being used for the purpose. Small parallel plates of hardened and tempered steel, called *drifts*, are then driven into the notches, in order to smooth the sides, and render them of uniform width. The gage used at Birmingham for iron wire, and for sheet-iron and steel, differs from the gage used for sheet-brass, gold, silver, &c.; and both these differ from the Lancashire gage for round steel wire. These gages appear to have come into use "without any attempt at system, either as regards the values of the intervals between the successive measures or numbers, or their correspondence with the subdivisions of the inch." [1] Besides this, gages nominally the same are made by different manufacturers without a sufficient agreement as to the unity of measure. Messrs. Stubs, of Warrington, who manufacture a large number of these gages, tested the drifts which they employ by means of a sliding gage, for reading off quantities to the $\frac{1}{1000}$th of an inch, by means of a vernier. The results of these admeasurements are stated in the following table. It must, however, be understood, that the three series of measures or gages bear no relation to each other: indeed, this will be sufficiently evident by comparing the number on one gage with the corresponding number on the other two gages: thus, No. 10 on the three gages is equal to ·134, ·024, and ·190, respectively.

VALUES OF GAGES FOR WIRE AND SHEET METALS IN GENERAL USE, EXPRESSED IN DECIMAL PARTS OF THE INCH.

Section I. Birmingham Gage for Iron Wire, and for Sheet Iron and Steel.		Section II. Birmingham Gage for Sheet Metals, Brass, Gold, Silver, &c.		Section III. Lancashire Gage for Round Steel Wire, and also for Pinion-wire. The smaller sizes distinguished by numbers, the larger by letters, and called the Letter Gage.					
Mark	Size	Mark	Size	Mark	Size	Mark.	Size	Mark.	Size.
0000	·454	1	·004	80	·013	40	·096	A	·234
000	·425	2	·005	79	·014	39	·098	B	·238
00	·380	3	·008	78	·015	38	·100	C	·242
0	·340	4	·010	77	·016	37	·102	D	·246
1	·300	5	·012	76	·018	36	·105	E	·250
2	·284	6	·013	75	·012	35	·107	F	·257
3	·259	7	·015	74	·022	34	·109	G	·261
4	·238	8	·016	73	·023	33	·111	H	·266
5	·220	9	·019	72	·024	32	·115	I	·272
6	·203	10	·024	71	·026	31	·118	J	·277
7	·180	11	·029	70	·027	30	·125	K	·281
8	·165	12	·034	69	·029	29	·134	L	·290
9	·148	13	·036	68	·030	28	·138	M	·295
10	·134	14	·041	67	·031	27	·141	N	·302
11	·120	15	·047	66	·032	26	·143	O	·316
12	·109	16	·051	65	·033	25	·146	P	·323
13	·095	17	·057	64	·034	24	·148	Q	·332
14	·083	18	·061	63	·035	23	·153	R	·339
15	·072	19	·064	62	·036	22	·155	S	·348
16	·065	20	·067	61	·038	21	·157	T	·358
17	·058	21	·072	60	·039	20	·160	U	·368
18	·049	22	·074	59	·040	19	·164	V	·377
19	·042	23	·077	58	·041	18	·167	W	·386
20	·035	24	·082	57	·042	17	·169	X	·397
21	·032	25	·095	56	·044	16	·174	Y	·404
22	·028	26	·103	55	·050	15	·175	Z	·413
23	·025	27	·113	54	·055	14	·177	A 1	·420
24	·022	28	·120	53	·058	13	·180	B 1	·431
25	·020	29	·124	52	·060	12	·185	C 1	·443
26	·018	30	·126	51	·064	11	·189	D 1	·452
27	·016	31	·133	50	·067	10	·190	E 1	·462
28	·014	32	·143	49	·070	9	·191	F 1	·475
29	·013	33	·145	48	·073	8	·192	G 1	·484
30	·012	34	·148	47	·076	7	·195	H 1	·494
31	·010	35	·158	46	·078	6	·198		
32	·009	36	·167	45	·081	5	·201		
33	·008			44	·084	4	·204		
34	·007			43	·086	3	·209		
35	·005			42	·091	2	·219		
36	·004			41	·095	1	·227		

1. The first column of the table refers to the gage used for most kinds of wire, and hence called the *Wire gage*; the *Birmingham wire gage*, and the *Sheet iron gage*. This gage is the most common of the three kinds specified in the table; it is used for iron, brass, and other wires, black steel wire, sheet iron, sheet steel, &c., and also for some manufactured works, including screws for joiners' use. The largest notch in this gage, marked 0000, measures 454 thousandths of an inch, or rather more than 4½ tenths of an inch: the smallest notch, marked 36, measures 4 thousandths, or $\frac{1}{250}$th part of an inch. Thus there are 40 terms in this gage; but there are in practice no less than 60 sizes of wire, intermediate ones being made. In some cases the sizes are retained while the numbers are altered; as in the wires drawn for the manufacture of needles. No. 1 of the needle wire

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(1) In the appendix to the second volume of Holtzapffel's work on Turning and Mechanical Manipulation, will be found a valuable paper, (which has been our chief authority in the present article,) entitled, "On the Gages at present used for measuring the thicknesses of Sheet Metals and Wires, and Proposals for a New System of Gages founded on the decimal subdivision of the Standard Inch."

corresponds with 18½ of the Birmingham wire gage: No. 2 needle-wire with 19 of the gage; $2\frac{1}{2}$ with $19\frac{1}{2}$; 3 with 20; 4 with 21; 5 with 22, and so on up to No. 21 needle wire, which agrees with 38 of the gage. In some cases half sizes of both series are interpolated, and the needles when manufactured are designated by another series of numbers, which bear no relation to either of these wire sizes. So also in the wire used for the strings of piano fortes, the sizes are known as Nos. 6 to 20, which agree very nearly with the sizes and half sizes of some of the notches of the Birmingham wire gages: thus the

Music wires, Nos	6,	7,	8,	9,	10,	11,	12,	14,	16,	18,	20,
and Birmingham gage, Nos	26,	$25\frac{1}{2}$,	25,	$24\frac{1}{2}$,	24,	$23\frac{1}{2}$,	23,	22,	21,	20,	19,

are respectively alike. The thinnest music wire, No. 6, measures about $\frac{1}{35}$th inch in diameter; and No. 20, the thickest, about $\frac{1}{25}$th inch. Pianofortes are strung much heavier than formerly, so that Nos. 1 to 5 have fallen into disuse. Steel wire is now used instead of brass. The covered strings are also of steel, with a fine copper wire wound spirally upon them.

2. The second gage in the table is the *Birmingham metal gage*, or simply the *metal gage* or the *plate gage* to distinguish it from the *wire gage*. It is used for most of the sheet metals, (except iron and steel,) viz. copper, brass, gilding metal, gold, silver, platinum, &c. The intervals in this gage are closer or smaller than those of the wire gage. Thus No. 1 is 4 thousandths or the 250th part of an inch wide, while the largest notch, No. 36, measures 167 thousandths, or very nearly $\frac{1}{6}$th inch. When thicker metals are wanted, their measures are sought in the wire gage: thus No. 36 on the plate gage nearly agrees with No. 8 on the wire gage, and the numbers 7, 6, 5, to 0000 of the latter are employed for thicker metals than can be measured by the plate gage. The plate gage often ends at 24, which agrees with 14 of the wire gage, and then the numbers 13, 12, 11 to 000 of the latter are used for thicker metals.

The method of describing sheet metals in commerce is liable to much variation. Thus

Sheet zinc,	Nos	6,	7,	8,	9,	10,	11,	12,	13,	14,	15, 16,
and Plate gage,	Nos.	4	$4\frac{1}{2}$,	5,	6,	7,	8,	9,	10,	11,	12, 13,

are nearly alike. These thin sheets of zinc measure from $\frac{1}{100}$th to about $\frac{4}{100}$ths inch thick, and are used chiefly for gutters, roofs, and small works. Thicker plates from about $\frac{5}{100}$ths to $\frac{18}{100}$ths thick, used for zincography, door plates and engraved works, are commonly made to the notches 18 to 7 of the wire gage.

When the value of the metal in sheet exceeds the value of the labour afterwards expended on it, such metal is estimated by the weight of every superficial foot. Thus, cast and milled lead are described as of from 4 to 12 lbs. the superficial foot, the variation being 1 lb. to the foot. Coppersmiths and braziers do not use the plate gage, but reckon their metal as from about 3 to 56 lbs. to the sheet of 2 feet by 4 feet. The precious metals are sometimes estimated by the number of ounces or pennyweights troy to the superficial foot.

3. The gages entered under section 3 of the table, are used for the bright steel wire prepared in Lancashire, and the steel pinion wire for watch and clock makers.

Many other gages are used in particular trades, such as the *rod iron gage*, the *nail rod gage*, the *button makers' gage*; others used in *watch work*; there is also the gage used by *gun makers* for the bores of guns and rifles.

The above mentioned gages are all arbitrary, having no reference to a fixed standard; so that regarding the various gages as a system, it is one of confusion instead of order and method as it ought to be. The simplest and least expensive remedy for this state of things, proposed by Mr. Holtzapffel, is to employ the decimal divisions of the inch, and those under their true appellations. "Thus for most purposes the division of the inch into 100 parts would be sufficiently minute, and the measures 1, 2, 5, 10, 15 or 100 hundredths would be also sufficiently impressive to the mind: their quantities might be written down as 1, 2, 5, 10, 15 or 100 hundredths, as the decimal mode of expression might if preferred be safely abandoned, and the method would be abundantly distinct for common use if the word *hundredths* were stamped upon the gage, to show that its numbers denoted hundredths of an inch, quantities which could be easily verified by all. It does not follow that the entire 100 notches should be at all times used, as in many cases it might suffice that below 20 hundredths every size should be employed; from 20 to 50 hundredths, every alternate size: from 50 to 100 hundredths, every fifth size. As at present also, the upper or lower part of the series of terms might be omitted to any desired extent in those cases where they were beyond the particular wants of the artisan or the particular branch of trade, in order to diminish the bulk and expense of the gage. It may be objected to this scheme that for the more valuable metals and the more minute purposes, the quantity of the one hundredth of an inch is too coarse a difference. Two facile modes of remedy may be here applied. The first, to make half sizes: thus $8\frac{1}{2}$ or 8·5 would of course denote the medial interval between 8 and 9 hundredths. Or, secondly and preferably, below one tenth of an inch, a finer scale might be substituted for the more minute and delicate purposes, namely a gage based, in precisely the same manner, on the *thousandth* of the inch as the unit which would give a much finer degree of subdivision than is afforded by any of the gages in general use; in this case the intervals being derived from the thousandth of an inch, the word *thousandths* should be stamped on every such gage."

For the advantages and applications of this method, we must refer to Mr. Holtzapffel's work, as also to a pamphlet published by him, "On a New System of Scales of Equal Parts."

GAGING, or GAUGING, is the method of determining by actual measurement the number of gallons contained in vessels intended to hold goods. These vessels are either of simple and regular figure, as in some casks which may be considered as the frusta of spheroids; or so irregular, that the content can only be found by dividing them into a considerable number of sections, and considering each section as a small cylinder or frustum of a cone. A writer in the Penny Cyclopadia, article Gauging, remarks on the old treatises on this subject, "The rules laid down were, in many cases, of uncertain application; as for instance, a close cask was to be treated either as a frustum of a spheroid or of a parabolic spindle, or as a double frustum of a paraboloid, or else of a double cone, according to its appearance. The allowance made for the thickness of a cask was a guess, and the method of using *small* sliding rules, to which supervisors formerly resorted to escape calculation, is a species of estimation which would never have been tolerated in money transactions between man and man. The inference to be drawn from the art, as described by early writers, is that, generally speaking, the results of excisemen's measurements were below the truth. . . . With *larger* sliding scales for calculation, and the aid of habit derived from experience, it is possible very accurately and easily to measure casks which do not depart much from a given standard of form. This is what is done by gaugers at the present time, and their practice has attained considerable accuracy. In a particular instance which has come to our knowledge, and in the case of a vat which held 6,500 gallons, the measurement of the exciseman did not differ more than ten gallons from the truth. This degree of accuracy is entirely modern, and must in a considerable degree arise from similarity of form being very nearly preserved in the different species of casks."

The most popular work on this subject was for a long time "The Practical Gager," by William Symons, compiled for the use of Excise officers. Warde's "Mathematician's Guide," and Hutton's and Bonnycastle's "Mensuration," contain small treatises on the subject.

GALBANUM, a species of gum-resin obtained from a perennial and apparently an umbelliferous plant growing in Africa, Syria, and Persia. It is imported chiefly from the Levant, in chests or cases of from one to three hundred pounds' weight. The best galbanum is in masses of whitish tears, agglutinated together, and having a strong balsamic odour: these are supposed to be the spontaneous exudation of the plant. The second sort is in dark irregular masses of inferior quality. Persian galbanum is very soft and tenacious, and is sometimes sent in skins. It often contains stalks and portions of the plant. Galbanum is used in medicine, as an antispasmodic, and is often associated with assafœtida, to which it possesses similar but inferior properties. Galbanum contains about 60 per cent. of resin, ($C_{40}H_{27}O_7$,) and 20 of gum, and yields, when distilled with water, a volatile oil, colourless and limpid, and having the odour of camphor.

GALENA. See LEAD.

GALL, or OX-GALL. See BILE.

GALLIC ACID, an acid obtained from nut-galls, [see GALLS,] which are to be powdered, mixed with water, and exposed for some weeks to the air at a temperature of 70° or 75°, water being added occasionally, to supply the loss from evaporation. During this time the powder swells and becomes mouldy. The mass, on being subjected to pressure, yields a quantity of coloured liquid: the cake which is left is then boiled in water, and the solution filtered while hot: on cooling, it deposits crystals of gallic acid, which may be purified by re-dissolving, and boiling with a small portion of animal charcoal. The filtered solution then deposits the gallic acid, in the form of white silky crystals. There are other methods of forming gallic acid, for which we must refer to chemical works. Gallic acid has a slightly sour astringent taste: it is soluble in about 100 parts of cold, and in 3 of boiling water: it is readily soluble in alcohol, and sparingly so in ether: it occasions no precipitate with gelatine. The formula for gallic acid is $3\,HO,\ C_{14}H_3O_7$. Heated to 212°, it loses 2 equivalents of water. This acid forms a number of salts called *gallates*. Tannic acid and tannin are noticed under LEATHER, Sec. II. p. 128.

GALLIPOLI OIL, a coarse olive oil imported from Gallipoli, a sea-port of the province of Otranto, in Italy.

GALLON, an old English measure of capacity. Until the year 1825 distinct gallons for wine, ale and beer, corn and dry goods, continued in use: thus the old wine gallon contained 231 cubic inches; the old corn gallon 268·6 cubic inches; the old ale gallon 282 cubic inches. The imperial gallon, as settled by the Act of 5 Geo. IV. cap. 74, contains 10 lbs. avoirdupois of distilled water, of which it is declared that 252·458 grains fill a cubic inch: consequently, the imperial gallon contains 277·274 cubic inches.

GALLS. GALL NUTS. The names given to hard, woody excrescences which form upon the shoots and branches of a diminutive species of oak, *Quercus infectoria*, common throughout Asia Minor, from the Bosphorus to Syria, and from the shores of the Archi-

Fig. 1017. GALL-NUTS.

pelago to Persia. These galls are produced by the punctures of an insect, *Cynips gallæ tinctoriæ*, which deposits its eggs in the vegetable tissue, and thereby causes the shoot or bud to swell, and become an excrescence or gall within which the larva is developed. When the insect is perfect, it eats its way out, and the gall has then lost much of its value. The best galls, known in commerce as *black* or *blue galls*, from their blueish tint, are gathered before the insect has escaped, and are of great importance as a source of black dye, and also as a material in the manufacture of writing-ink. The *white galls*, or those from which the insect has departed, answer the same purposes in an inferior degree: they are larger than the blue galls, but less heavy and astringent; their colour is a brownish or dingy yellow, and they are perforated with a small circular hole, through which the insect made its escape. It is not an uncommon fraud to dye the whitish gall-nuts blue to increase their value, but this is soon detected by the colour being deeper than is natural, and also by the deficiency of the galls in weight, and by their perforation.

In the cultivation of the crop, great care is taken by the orientals to gather the galls at the time when they have attained their full size and weight. Any delay at this period is very injurious, giving the insect time to undergo its final metamorphosis, and to pierce the shell. The Aga of the district levies a tax on the produce, and is therefore interested in its success. He causes the cultivators to traverse the hills and mountains frequently, at the time of harvest, and watch carefully the progress of the galls on the oaks, which grow freely in such situations. The gall-nut is very hard, generally round, and covered with knots, some of which are pointed. The size varies from that of a pea, to that of a nutmeg. Galls are without smell, but they have a disagreeably bitter taste, and a powerful astringent action. They were used in medicine in the time of Hippocrates, and are still so employed to a certain extent, though their most extensive use is in the arts and manufactures, and as a chemical test.

The best galls come from Aleppo and Smyrna. In 100 parts of Aleppo galls Sir H. Davy found gallic acid 6·2; tannin 26; gum and insoluble tannin 2·4; lime and other salts 2·4; woody fibre 63. The galls occasionally brought from India are not the produce of that country, but are carried thither from Persia by Arabian merchants. Galls have been largely imported for many years; but a less expensive substitute is now greatly in request. This consists of the cups of the acorns of another species of oak, (*Quercus ægilops*, or the Velani oak,) which are found to partake of the nature of the gall-nut. The acorns of this oak are short and thick, and the cups very broad, and closely beset with oblong scales. The cups are known in commerce as *valonia*, and form an important article of trade from Smyrna and its neighbourhood. A fruit called Myrobalans, and resembling in appearance dried plums, is much used by the Hindoos as a substitute for galls, the useful properties of which it appears to possess.

Gall insects are remarkable for the wonderful mechanism which enables them to puncture the different parts of plants. Whether they produce the berry-shaped excrescences known as oak-apples, or the tuft of reddish-brown hair which forms the gall of the rose, or the artichoke galls of the oak-bud, or the leafy gall of dyer's broom, or the rose-like clusters which give their name to the rose-willow, or the woolly balls on the hawthorn, or willow, or the currant-gall produced on the catkins of the oak,—the machinery employed is always the same, though the species of gall-insect varies in each example. This machinery consists of a needle contained in a sheath, and having remarkable powers of extension derived from the peculiar construction of the body of the insect; so much so, that the needle can be extended to twice the length of the insect itself, within which it is lodged in a bent form, following the curve of the body, and running from its base near the anus, along the back, making a turn at the breast, and then assuming the curve of the belly and appearing again near the point whence it had originated. This curious structure, which is common to the various members of the genus Cynips, has been closely examined and described by Réaumur.

Some Chinese galls, subjected to examination by Mr. Doubleday, are stated to have contained minute insects, belonging to the family of the aphidians. The galls, on being broken, were mostly found to contain a quantity of white, downy-looking matter, and numerous little rounded dark-brown substances, not bigger than grains of coarse sand. These black or brown atoms were the insects whose puncture had produced the gall, and the downy matter was their peculiar white secretion. From their desiccated condition, and long shaking about, the down had become detached, and most of the legs and antennæ were broken off. The nature of the shrub which produces these galls has not yet been ascertained.

GALVANISM. The most important applications of this beautiful science will be found under Electric Telegraph — Electro-Metallurgy — Electro-motive Machines.

GALVANISED IRON. See Amalgam—Electro-Metallurgy.

GAMBOGE. See Camboge.

GANGUE, the mineral substance which encloses or accompanies any metallic ore in the vein. Quartz, lamellar carbonate of lime, sulphate of baryta, sulphate and fluate of lime, are common gangues; but many other substances become such when they predominate in a vein. The word is pronounced *gang*: it is from the German *gang*, a vein or channel.

GARNET, a vitreous mineral of the cubic system, composed of three or four silicates—those of alumina, lime, iron, and manganese; the varieties of colour being due to their varying proportions and combinations. The best specimens are called *precious* or *noble garnets*: these are of a clear, deep red, and are cut quite thin on account of their depth of colour. They are chiefly brought from Pegu, and are of considerable value. A variety of this stone is supposed to have been the *carbuncle* of the ancients, and identical also with the *hyacinth*. Common garnet is very abundant, and of various colours, but is rarely fine enough to be employed with good effect in jewellery. In some parts of Germany, garnets are so abundant as to be used as a flux to some iron ores. They are also pounded, and used as a substitute for emery.

Garnet is usually met with in the forms of dodecahedrons and trapezohedrons, but these may be variously modified. It is also found in granular masses. The sp. gr. varies from 3·35 to 4·24.

GAS, the generic name of all those elastic fluids which are permanent at low temperatures. In this respect they differ from vapours, which become liquid or solid on reducing the temperature. The difference, however, is only one of degree; for Faraday has succeeded in liquefying many of the gases, and solidifying a few of them, under the influence of cold and pressure. [See CARBONIC ACID.] For the physical properties of gases, we must refer to AIR. The most important gases are described under their respective names.

GAS-LIGHTING. An inflammable air, capable of affording light and heat, is formed naturally in many parts of the world. At Baku, on the shores of the Caspian Sea, the "holy fires," as they are called, are produced by the combustion of gas which issues from the earth. The burning fountain of Dauphiné is of similar origin: in Italy, Hungary, Greece, England, America, and China, natural springs of gas occur. In China these natural gasometers are profitably applied in boiling and evaporating the salt brine obtained by boring; other tubes convey supplies of the gas for lighting streets and houses, and the excess is got rid of by burning in a chimney beyond the limits of the salt-works. In the month of December, 1851, the newspapers contained an account of a large blaze of natural gas on Chat Moss, on the line of railway between Manchester and Liverpool. The gas was liberated in boring for water: the first 16 feet being through moss and peat, and the next 16 feet through marl: then followed 2 or 3 feet of sand; and while scooping through this portion the gas suddenly appeared, with a loudish noise and a slight sulphurous smell. A stream of gas then floated along the surface of the ground, which took fire on the application of a light. A pipe, 10 or 12 inches in circumference, was then inserted into the ground to the depth of 2 or 3 feet, and with a height of about 36 feet, by which means the gas was conveyed above the level of the neighbouring forest trees: it burnt at the top of the tube with a flame apparently 8 or 9 feet long: its colour was yellowish mingled with blue tints: the light was strong enough to allow a person at the distance of 100 yards to see the time by his watch. On applying the ear to the pipe, the sound of the gas traversing it could be heard like the sound of rushing water. The flame was afterwards extinguished by the wind.

This gas is probably the *light carburetted hydrogen* of chemists (CH_2), the *fire-damp* of the coal-pit, and also known as *marsh-gas*, from the circumstance of its being found abundantly in stagnant pools during the spontaneous decomposition of vegetable matter. So long since as the year 1659, Thomas Shirley attributed the exhalations from the burning well of Wigan in Lancashire to the subjacent coal-beds; and a few years later Dr. Clayton, Rector of Crofton, at Wakefield in Yorkshire, actually prepared gas by the distillation of coal, washed it in water, collected it in bladders, and burnt it from a jet. And yet, notwithstanding this suggestive experiment, which was communicated to the Royal Society, considerably more than a century elapsed before gas-lighting took its place among the industrial arts. In 1770 a spontaneous evolution of gas took place at a colliery near Whitehaven, which was kindled, and burned with a flame more than 2 yards long. This was noticed in the Philosophical Transactions for 1773, about which time Dr. Hales and also Dr. Watson obtained gas by the distillation of coal. In 1786 Lord Dundonald erected coke furnaces and burned the gases in tubes for the amusement of his friends, but apparently without any other object. In 1792 Mr. Murdock employed coal-gas for lighting his house and offices at Redruth in Cornwall; and in 1802, on the occasion of a general illumination, he lighted up part of the Soho manufactory near Birmingham, belonging to Boulton and Watt, with a display of gas-lights. In 1804 and 1805 the same gentleman lighted with gas the cotton-mills of Messrs. Philips and Lee at Manchester, and distributed a quantity of light over the building equal to nearly 3,000 candles. This was the first extensive application of coal-gas to the purposes of illumination, and it soon became general. About this time Mr. Winsor went about giving lectures on the subject, and gradually overcame the ridicule and incredulity which were opposed to his plan of lighting a whole city with gas. In 1812 a part of London was lighted in this way; and in 1815 the method was introduced into Paris. About the year 1804 Mr. Samuel Clegg began to devote his attention to the subject, and he afterwards rose to eminence as a gas engineer.

The light carburetted hydrogen above alluded to is a gaseous compound of carbon and hydrogen, 100 parts by weight containing 75 of carbon and 25 of hydrogen. The illuminating power of this gas is far inferior to that of another compound of these two elements, called *bicarburetted hydrogen*, or *olefiant gas*; it contains twice as much carbon as the former gas in the same bulk. Olefiant gas does not occur naturally: it is obtained by the destructive distillation of oil; and it is also obtained together with light carburetted hydrogen and other substances more or less luminous, when coal, resin, tar, asphaltum, fat, animal refuse, and similar inflammable matters, are distilled for the purpose of obtaining gas for artificial illumination.

In this country gas is usually produced from coal, which must be bituminous in quality: cannel coal produces good gas in large quantity; next to this is Scotch parrot coal. By a rough estimate, 100 cubic feet of coal yield from 18,700 to 9,200 cubic feet of gas, according as the best kinds of Scotch or Lancashire coal are used, or the worst kinds of Staffordshire coal.

But perhaps the richest gas-making coal in the world (if *coal* it may be called) is that known by the name of *Boghead cannel*. It is stated by the proprietors, in their advertisement for the sale of this article, that "it is the most highly bituminous coal known, and therefore well adapted for mixing with inferior coals in the manufacture of gas. It yields 13,500 cubic feet of gas, of the sp. gr. ·775, per ton; and a burner consuming at the rate of 1 cubic foot per hour gives a light equal to 8½ spermaceti candles each consuming 120 grains of sperm per hour." This so called cannel coal is a variety of clay or shale saturated with bitumen. Its mean specific gravity is 1·247; it is hard and tough, and when broken shows a conchoidal fracture; the colour varies from blackish grey to brown; the surface appears earthy and has no lustre; a chip of it takes fire by holding it for a moment in the flame of a candle, and burns easily. When heated below redness in a glass retort, it yields combustible gases, as well as a large amount of volatile combustible liquids, holding in solution much solid combustible matter.[1] No ammonia is produced during the distillation. There is left in the retort after all volatile matter has been expelled, a black mass which, when heated in the open air, is found to consist of earthy ingredients, principally silicate of alumina, the remainder being carbon. The mean of three analyses of this coal gave, volatile matter 68·12, ashes 27·75, carbon 4·13. Boghead is situated about half-way between Edinburgh and Glasgow, and the coal occurs close to the large village of Bathgate, which is increasing in prosperity owing to its discovery. It is exported largely from various ports of the Frith of Forth to England, the Continent, and even to South America.

The production of the gas depends upon the application of a high temperature to the coal. At a moderate heat, such as 100° Fahr., the volatile constituents of the coal pass off in the state of fluid hydrocarbons or naphtha, with little or no admixture of permanent gas. At a cherry-red heat, or a little higher, there is an abundant production of gas, with only a small production of tar and naphtha.

The coals must not be wet, or when suddenly exposed to a red-heat the outer portions will become coked long before the water in the centre of the coal is expelled: consequently, as the heat penetrates the coal, this water is converted into steam and driven over the red-hot coke, thus leading to the production of hydrogen, carbonic oxide, and carbonic acid, the first two of which dilute the gas and lower its illuminating power,[2] while the third only serves to neutralize the lime when the gas is passed through the purifier. The conversion of the water into steam by the absorption of sensible heat, lowers the temperature towards the point more favourable for the production of tar or naphtha than of gas. At too high a temperature, on the contrary, the rich olefiant gas is decomposed into light carburetted hydrogen and carbon, the latter often lining the gas-retort in distinct layers, an inch or more in thickness. The iron pyrites of the coal forms, at a low red-heat, protosulphuret of iron and free sulphur; and the latter, uniting with the hydrogen of the coal, forms sulphuretted hydrogen. The nitrogen of the coal uniting with a portion of its hydrogen forms ammonia. Hence it will be seen that the distillation of coal leads to complicated results.

The coal is distilled in tubes of cast-iron, called *retorts*; they are usually about 7 feet long, and 1 foot in diameter. Before being used they are tested by being placed in water, and then forcing air through them: if any flaw exist it is detected by the air escaping in bubbles. Each retort is usually in two pieces, which are connected by flanges and screws; namely, the *neck*, or *mouth-piece*, and the *body*, or hinder part, which by constant exposure to the fire soon wears out and requires renewal, while the mouth-piece is but little acted on. The retort is charged and discharged at the mouth, which is closed by a lid, and fixed by means of a screw and a hold-fast, Fig. 1018; the joint being made tight by a luting of clay or of lime from the purifier. The gases which are generated from the coal escape from the retort by a wide tube cast into the mouth-piece, and shown in Fig. 1018 rising up therefrom. The best form for the body of the retort, for obtaining the largest quantity of gas in the shortest time, was long a matter of discussion. The first retorts used on the general introduction of the system were in the form of a circular tube, Fig. 1019, *a*, a form still used with cannel coal: these were for the most part superseded by the elliptical form, *b*, which was further improved by bending in the lower surface into a *kidney-shape*, as at *c*, whereby a much larger portion of the charge is brought into contact with the red-hot sides than in the other forms. The breadth of kidney-shaped retorts is usually from 20 to 22 inches, and

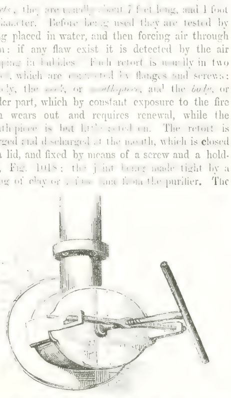

Fig. 1018.—MOUTH OF THE RETORT, SHOWING THE METHOD OF FASTENING.

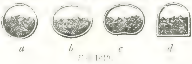

Fig. 1019.

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[1] This substance, also called *Torbanehill mineral*, is also used for the production of PARAFFINE and PARAFFINE OILS. See APPENDIX.

[2] Attempts have been made to turn this process to useful account in the production of what is called *water-gas*, as will be noticed further on.

the height in the middle from 9 to 12 inches. In all three forms, with the same length of 6½ feet exposed to the fire, 150 lbs. of coal, only half-filling the retort, will cover in the round form a red-hot surface of 10 inches in width; in the oval form, a surface of nearly 12 inches, while the charge is much nearer the top of the retort than in the circular form. It is stated that this variation in form has reduced the time required for heating one-half; that the average quantity of gas obtained from a ton of Newcastle coal in the elliptical or the kidney-shaped retort is 9,000 cubic feet; while in the circular retort only 6,400 feet have been obtained. D-shaped retorts, Fig. 1019, *d*, are also in common use.

The retorts are heated in furnaces; 5 retorts being usually arranged in one furnace, two and two, and one above; and each furnace has two separate fires, the brickwork being so arranged as to divide and distribute the flame among the retorts, coke and coal being the fuel. At most works the furnaces are arranged in rows on each side of the retort-house, their flues meeting in a central chimney. In extensive gas-works there are from 400 to 600 retorts, of which from 200 to 300 are worked on the average of summer and winter, each retort being charged with about 120 lbs. of coal every 6 hours. Two men attend to 3 furnaces of 5 retorts each, and as the retorts are kept constantly at work, the men work in shifts of 12 hours at a time, with intervals for rest and meals; they are not actually engaged at work more than half that time. The tubes which rise from the retorts R R, Fig. 1022, are recurved at the top, and dip into a large horizontal tube H, called the *hydraulic main*.

The improved scientific knowledge of the gas-maker enables him to arrange a much larger number of retorts in one furnace. At the Great Central Gas-works, Bow Common, under the intelligent management of Mr. Croll, no less than 13 retorts are heated by one furnace-fire. They are disposed in the manner shown in Fig. 1020: the furnace-fire is placed in a central position; the upper series of 6 retorts are heated by the radiation of the fire; the other 7 retorts are heated by the hot draught descending in the direction of the arrows. These retorts are each 18 feet in length from the face of the brickwork setting, and they are charged and discharged at both ends. The upper series of retorts are made of fire-clay; 4 of which are circular, and 2 oval in shape, with circular iron mouth-pieces. The lower series of retorts are of iron; each retort with its mouth-piece being formed in one casting, 19 feet 6 inches long. The clay retorts will bear a stronger heat than the iron ones, and being situated in the same arch with the furnace, are exposed to a much greater heat, which admits of their being charged every 4 hours; the iron ones are charged every 6 hours. The average yield of gas per day at these works, from each double retort, 18 feet in length, is 8,500 cubic feet. Retorts made of fire-clay retain their heat at nearly the standard temperature when a fresh charge of coal is introduced, and their superior durability compared with iron retorts compensates for the slight increase of fuel which they require. It is difficult to maintain iron retorts at a uniform high temperature, and to prevent their being burnt out faster in one part than in another, especially in the old arrangement, where the furnace-fire is large, and the retorts are few in number, and far asunder. In the new arrangement one cannot help being struck with the large number of retorts in a small space, whereby a great saving is effected in the superficial space required for the retort-house: there is also a great economy of fuel; one ton of coals in the retorts being carbonized with only 12 to 15 per cent. of fuel, as compared with 25 to 35 per cent. in ordinary practice. The iron retorts also last longer, the flame being more generally diffused by the downward draught. The carbonaceous incrustation can

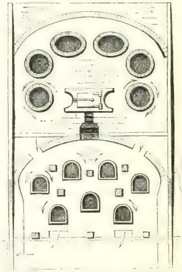
Fig. 1020. ARRANGEMENT OF THE RETORTS.
(Front elevation, exterior.)

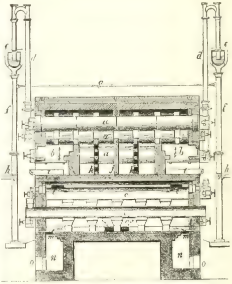

Fig. 1021. ARRANGEMENT OF THE RETORTS.
(Side elevation, in section.)

also be much more easily removed from the interior of the retorts, in consequence of their being open at each end. The usual make of gas at these works is 900,000 cubic feet per day, to produce which twelve settings are in use. These occupy an area of 18 feet in width by 124 feet in length, and are capable of producing 1,200,000 feet a day. The retorts reach from end to end of the setting, being more than double the ordinary length, and they are fired and charged from each end. In Fig. 1021, *a a* are the clay retorts, arranged round the furnaces *b b*, and exposed to the immediate contact of the flame; *c c* are the cast-iron retorts, arranged beneath the furnace, and heated by the current of hot air, which in descending diffuses itself equally over the lower set of retorts. Hence, while the clay retorts are exposed to the fiercest heat of the furnace, the cast-iron retorts encounter a milder temperature, suited to their superior conducting power; and hence, instead of discharging flame and intensely heated air into the chimney, as is done by the old method, the arrangement of the retorts and the descending draught leads to the economy of fuel already noticed. The close setting of the retorts does not allow all the pipes *d d* to ascend from one end into the hydraulic main; they are therefore carried off some at one end and some at the other, and descend into the two hydraulic mains *e e*. These mains are cast in lengths equal to the distance between the centres of the sets of retorts, and are carried by the hollow columns *f f*, which are tied together across the retort setting by tie-rods, *g*. These columns also serve to carry the girders *h h*, and the cast-iron platform upon which the upper retorts are worked. The space below this platform (Fig. 1024) is used in working the iron retorts, as well as for receiving the coke from the clay retorts; sufficient space being left between the edge of the platform and the brickwork to allow the coke from the upper retorts to fall down into the coke *omnibuses*, in order to be conveyed to the coke heap. Wrought-iron water-troughs, *i i*, are used, to keep the fire-bars cool: there is only one fire-bar to each furnace, and this is of round iron for the easier separation of the clinker. A partition-wall *j* extends completely across the arch, to divide the two furnaces, and thus prevent one furnace drawing into the other. The walls *k k* serve to carry the retorts, and are perforated with holes for the passage of the draught. The spaces *l l* in the lower arch form the communication between the upper and lower settings; the draught, after surrounding the lower retorts, passing through the openings *m m* into horizontal flues *n n*, which run the whole length of the retort settings, and communicate with the main flue which enters the chimney. Dampers formed of fire-tile slide over the openings *m m*, to adjust the draught, and flue-doors *o o* are provided for cleaning out the flues *n n*.[1]

Now supposing the retorts to be at a bright-red heat, and just charged, the first action of the heat is to expel the atmospheric air from the retorts, and moisture from the coals. As the coal becomes hot a considerable quantity of tar distils over into the hydraulic main, together with a portion of gas consisting chiefly of hydrogen and ammonia. The gas constantly increases in quantity; tar and ammoniacal liquor pour over together, with a portion of sulphurous acid from the pyrites of the coal. The gases are most abundantly disengaged when the retorts are kept at a bright cherry-red heat: it has been computed, that in 8 hours' distillation with a uniform fire and the retorts at a constant red heat, the relative quantities of gas given off, on a per centage of the whole charge, are in the first hour 20, in the second 15, in the third 14, in the fourth nearly 13, in the fifth 12, in the sixth 10, in the seventh 9, and in the eighth about 8. At these different periods, however, the qualities of the gaseous products are very different: the gas which comes off before the retorts have acquired their proper temperature burns with a feeble light; the best gas is given off when the retort has just acquired a vivid-red heat, for the gas then consists chiefly of carburetted hydrogen and olefiant gas, 100 measures of the gaseous products containing 82.5 of carburetted hydrogen, 13 of olefiant gas, 3.2 of carbonic oxide, and 1.3 of nitrogen. By continuing the distillation the valuable gases diminish in quantity; and those which burn with little or no light, such as hydrogen, sulphuretted hydrogen, and carbonic oxide, and those which do not burn at all, but extinguish flame, such as nitrogen and carbonic acid, increase in proportion.

The tar which distils over into the hydraulic main, covers the mouths of the conducting tubes, as shown in Fig. 1022, by which means the retorts are prevented from communicating with each other, so that any one may be opened and charged without interfering with the others. The tar is prevented from accumulating in the hydraulic main by means of a syphon tube, so arranged as to carry it off into the tar-cistern as it rises above half the horizontal section of the main; but by turning a cock at one extremity of the main all the tar can be drawn off.

When the distillation of the coal is carried as far as it is thought desirable, the lid of each retort is loosened, and the gas ignited at the mouth: if the lid were at once removed, the air rushing in might form an explosive mixture with the gas in the retort, and thus lead to accident. When the lid is removed, the remainder of the gas burns out at the mouth; the glowing coke is then raked out into an iron carriage, called a *coke omnibus*, moving on a line of railway in front of the furnaces. As soon as the coke falls into the carriage, water is dashed upon it to quench it. The retort is then cleared out by means of hoes or scrapers with very long handles, the retort all the time retaining its cherry-red heat. A long auger is also passed up the pipe leading into the hydraulic main, to clear away condensed tar, which if allowed to remain would prevent the distillation from going on. Each retort is recharged by means of a long curved tray of sheet-iron, Fig. 1023, called a *scoop*; this is filled with coal and pushed to the end of the

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(1) See the *Artisan* for 1851, with reference to the Great Central Gas-works. For an account of the manufacture of clay retorts, see POTTERY and PORCELAIN, Sec. III.

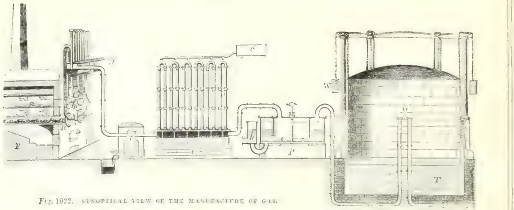

Fig. 1022. SYNOPTICAL VIEW OF THE MANUFACTURE OF GAS.

retort, inverted so as to turn out the coal, and then withdrawn. A portion of the coal is immediately converted into gas, which pours out at the mouth in a copious flame; but this is soon checked by the cover, previously luted, which is quickly screwed on, and the distillation proceeds as before. "This discharging and recharging of the retorts is a very hot and disagreeable duty, and has a remarkably picturesque effect, especially during the quiet of a clear calm night: the growing heat of the furnaces, the bursting flames of gas when the retorts are opened, the rush of black smoke and flame which accompanies the fresh charge, the workmen with their long rakes and shovels, the shadows of their naked bodies appearing dark-green upon a red ground; the striking effects of light and shade; the noise, the exertion, the turmoil, the suffocating heat and odour alike oppressive,—all this is in striking contrast with the refreshing coolness and calmness of the sky seen through the openings of the gas-house. The effect is perhaps equally striking, although in another way, on a bright day, when the beams of sunshine penetrating the gloomy retort-house through chinks in the roof, are so loaded with smoke, and steam, and dust, as actually to appear like solid masses of matter. When the retorts are charged, and the fresh coke has been wheeled away to the heap, the noise, the dazzling bursts of flame and much of the heat, subside into a more quiet and sober scene, but still the heat and the loaded atmosphere of the place are oppressive, and the writer has always felt more relief in quitting a gas-house than any other factory which it has been his pleasant duty and privilege to visit in preparing these treatises for the press."[1]

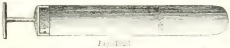

Fig. 1023.

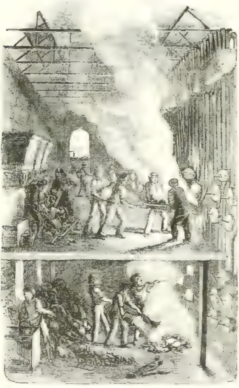

Fig. 1024. THE RETORT-HOUSE. (*Great Central Gas-works.*)

Most of the tar and ammonia of the coal condense in the hydraulic main and are disposed of in the tar cistern: the hot gas, which also passes into the main, holds in suspension a considerable portion of the vapour of these substances, which must be immediately got rid of, or they would in cooling condense in the distant parts of the apparatus, and stop up the pipes. The hot gas is therefore made to pass from the hydraulic main to the coolers or condensers, a common form of which consists of a number of upright tubes, encased in larger ones containing water, which is kept cold by constantly flowing in at the bottom, and being heated by the tubes through which the hot gas is circulating, escapes in a stream at the top. Another form, shown at Fig. 1022, is the *air*-condenser, in which the enclosing tubes of water are dispensed with, and the cooling is assisted by cold water from the cistern

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[1] Tomlinson's Useful Arts and Manufactures of Great Britain Vol. ii.

C, trickling down over the tubes: but in this case a larger amount of cooling surface is required, which is provided by 20 or 30 lofty tubes. The gas in passing through these cooled tubes is considerably reduced in temperature, and the vapour of tar, &c. condenses into a liquid, which trickles down into the divisions of the iron chest at c, whence it flows back into *t*, and can be drawn off from time to time by the tap into a pit or sunk cistern. The gas enters the condenser at the temperature of about 120°, and leaves it at about 60°.

The gaseous and vaporous products of the distillation, by their elasticity consequent on their high temperature, force for themselves a passage from the retorts into the condenser, &c. This pressure, however, is objectionable, because should a retort be cracked or be badly secured, much of the gas would escape and be lost; or should any of the pipes become choked with tar, the increasing elasticity of the accumulating gas might lead to dangerous explosions. To avoid such inconveniences, an *exhauster*, consisting of a pumping apparatus, is at some works introduced between the condenser and the lime purifiers, the effect of which is to relieve the retorts from internal pressure by causing the gas to move through the condensers and propelling it forward to the lime purifiers.

The impurities which are got rid of by passing the gas through lime, are sulphuretted hydrogen and ammonia, the latter in combination with carbonic, muriatic, sulphuric and sulphurous acids. There are two kinds of purifiers, the wet and the dry. In the wet lime purifier, the gas on leaving the condenser passes through the inlet pipe A, Fig. 1025, into the chamber B, which, with the hoop D, forms a sort of inverted funnel, which is supported by the iron beams C. The outer vessel contains a mixture of lime and water, called *milk of lime*. The gas on entering depresses the lime water in the funnel, and then escapes through numerous minute apertures into the liquid, where the bubbles are dashed about and brought into intimate contact with the lime by means of a stirrer, E *e*, revolving rapidly round on the spindle S, passing through a stuffing box G, by wheel and pinion work H. As the lime-milk becomes saturated with the impurities of the gas, it is drawn off by a pipe I, and, by opening a slide-valve K, the lime-water can be completely drained off, without allowing the gas to escape with it. A fresh supply of lime-water is introduced by means of the cistern lead L. F is the outlet pipe. The quantity of lime used must depend upon the per centage of sulphuretted hydrogen and carbonic acid in the gas. If, for example, there be 5 per cent. of these gases, about 1½ lb of lime will be required for every 100 cubic feet of gas. In some works three purifiers placed at different elevations are used in succession, the last of the series being the most elevated. From this the lime water overflows into the second, and from the second into the first. By this means the gas is brought into contact with lime of gradually increasing purity, and is thereby more completely purified. The spent lime, which is of an excessively fetid odour, is not allowed by law to be thrown out as refuse; it is evaporated in the ash-pits of the furnaces, and then used as mortar for luting the retorts, &c.: it is also sold for mortar, for manure, and for the use of the wine-bottle glass-blower.

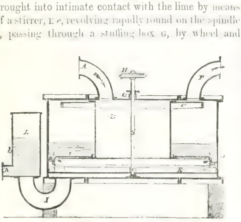

Fig. 1025. WET LIME PURIFIER.

Dry lime, or, more properly, hydrate of lime, is now usually employed in the purification of gas. In the dry lime purifier, the gas is let in by the pipe A into the bottom of a rectangular iron vessel about 3 feet deep: over the mouth of the inlet pipe is a plate of iron, B, to separate the gas, and prevent the lime from falling into the pipe. This vessel is in some cases divided into two compartments by a partition extending not quite to the top: the gas filters up through one compartment and down through the other, passing each way through several layers of lime, C C, placed on iron gratings, or perforated shelves of cast iron, 7 or 8 inches apart. The perforations are each $\frac{3}{8}$ inch in diameter, and ¾ inch asunder. The purifier is covered with a light lid of sheet-iron. The lime being fresh slaked and slightly moistened, is placed on each shelf to the depth of about 3 inches, and then sprinkled with water from the rose of a watering pot. A bushel of quicklime is said to be sufficient for the purification of 10,000 cubic feet of gas. By slaking and reducing it to a proper consistency for use, its bulk becomes more than double; two bushels of the hydrate thus formed will cover a surface of 25 square feet, to a depth of 2½ inches, this being the thickness which answers best. At some works a bushel of slaked lime, or half a bushel of unslaked lime, is allowed for every ton of coals that

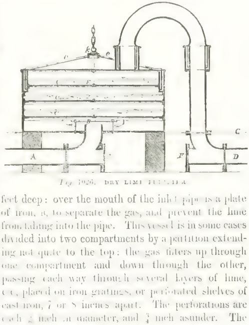

Fig. 1026. DRY LIME PURIFIER.

is distilled. According to another estimate, 40 lbs. of lime are required for every 10,000 cubic feet of gas from Newcastle coal of average quality. If more lime be used the coal must have been damp, or have contained more than the usual average of sulphur. Good Newcastle coal contains about 1 per cent. by weight of sulphur; some kinds of cannel, only ½ per cent. The gas is usually passed through two, three, and even four dry lime purifiers, all constructed on the same principle. In Fig. 1026, D is the outlet pipe, leading to the second purifier G. The movable top or cover of each purifier fits into a water joint or trough, 10 inches deep and 6 inches broad. The shelves are also movable, the upper ones being taken out while the lower are being charged. The spent lime, which contains hydrosulphuret of ammonia, is very offensive, on account of its evolving sulphuretted hydrogen in contact with the atmosphere, the carbonic acid of which takes its place. This is entirely removed before the purifiers are emptied, by connecting each purifier by means of a joint with a large horizontal pipe which opens into the chimney-shaft of the retort house, the powerful draught of which rapidly exhausts the air from the horizontal pipe, and all the offensive volatile matters of the lime escape from it, as into a vacuum, and are speedily decomposed by the hot air of the chimney. After this, the cover of the lime purifier can be raised by means of the chain *k*, attached to the light rods *e e*, and the purifier be cleaned out without any annoyance to the men or to the neighbourhood. The lime thus removed is burnt in ovens, and used a second time in the purifiers, after which it becomes refuse. F F are blank flanches, which, when removed, allow the pipes to be cleaned out.

The lime removes from the gas carbonate of ammonia and carbonic acid about 2 per cent., and sulphuretted hydrogen about 1 per cent.; varying with the nature of the coal and its dryness. If the gas be properly purified, it ought to return good answers to the following tests:—turmeric paper moistened and held in a jet of the gas ought to retain its yellow colour; if the gas contain ammonia, the yellow will change to reddish brown; or blue litmus paper, slightly reddened by an acid, will have its colour restored; if there be no ammonia the red will remain. A paper dipped in a solution of acetate of lead, and held in the gas, will turn black if sulphuretted hydrogen be present; if the gas be made to pass in bubbles through lime-water, a milkiness will be produced if carbonic acid be present. It usually happens, however, that after the gas has passed through the lime purifiers, it still contains a little ammonia; this would be absorbed by the water of the meter, if it could be kept long enough in contact therewith. As this cannot be done, it is disposed of more quickly by passing the gas through a solution of alum or of green vitriol, or through dilute sulphuric acid: chloride of calcium, and other substances, are also used for the purpose. A water washing is, however, quite sufficient, if it be properly managed. At some works the gas from the purifier is conducted to the bottom of a tank called a *scrubber;* this is filled with coke for the purpose of greatly increasing the surface, and water being introduced at the top by a horizontal perforated tube, trickles slowly down over the coke, while the gas passes in the contrary direction. At some works this gas is mixed with steam, and being exposed to a low temperature, the steam is condensed in drops, whereby the gas is exposed to a considerable liquid surface.

The economic value of ammonia as a manure has led to attempts of late years to condense the whole of it in an unobjectionable form, so as to make it available. By Johnson's method the gas is purified by exposure to a compound of sulphate and biphosphate of lime, prepared by acting on burnt bones with sulphuric acid. This compound is disposed in trays in such a manner as to absorb the ammonia of the gas passed over it, thus forming a mixture of sulphate of ammonia and phosphate of lime, which is of course a valuable fertilizing material. By Laming's process, a solution of chloride of calcium, or muriate of lime, absorbed into saw-dust, is used, by which means the muriate of lime is gradually decomposed, and carbonate of lime and muriate of ammonia are formed, which are used as manure, or in the manufacture of sal ammoniac. Sulphate of lime, and various other earthy and metallic salts, such as the sulphates of magnesia, alumina, zinc, iron, and manganese, and chlorides of the same substances, have all been, or are now being used for the purification of coal-gas. At the Great Central Gas-works a solution of chloride of manganese is used. It is said to be effectual in purifying the gas from ammonia, and also absorbing a portion of the sulphuretted hydrogen, economising the lime to the extent of 30 per cent.

The use of the scrubber before the lime purifier, as is done at the Westminster works, leads to a considerable saving of lime, for there is an absorption of the ammonia, and the prevention of its reaction on the carbonic acid in the lime purifier, whereby carbonate and hydro-sulphate of ammonia are formed. Laming's plan can only be used before the gas passes into the lime purifiers.

Supposing the gas to be sufficiently purified, it is next passed through the station meter, which registers the quantity of gas made at any given hour of the day or night. This meter is similar in principle to the consumer's meter, hereafter to be described. Attached to it is a *tell-tale*, which serves the purpose of pointing out every irregularity in the production of the gas during the 24 hours. In the centre of the *dial-field* is fixed a circular plate, connected with a train of wheel-work, set in motion by an enclosed drum, through which the gas passes, indicating tens, hundreds, thousands, &c. of cubic feet of gas. Upon this circular plate is fixed a disc of paper, divided into 24 parts, with subdivisions. Suppose the meter to register 300,000 cubic feet in 24 hours, and the plate to be connected by wheels in the ratio of 3 to 1 to that index, which marks 100,000 in one revolution; it is evident that the distance travelled by one of the 24 divisions of the plate, from a certain fixed point, will indicate the quantity of gas made in one hour, or $\frac{300,000}{24} = 12,500$ cubic feet. Above this divided disc is a time-piece, to the minute-hand of which is attached a detent, furnished with a pencil, pressing by a spring upon the disc. As the minute-hand of the time-piece revolves, the pencil, by means of a guide fixed to the meter-case, is regulated, so that in the first half-hour it will make a vertical line upon the paper, in length equal to the diameter of the circle formed by the minute-hand, measured from the centre to the point at which the detent is fixed; in the second half-hour the line will be retraced by the hand rising again. This arrangement supposes the divided disc to be stationary; but as it is made to revolve upon an axis which is also the axis of the internal drum, set in motion by the gas, the pencil will make a series of curved lines, meeting the divided circle of the disc every hour, and the distance travelled from point to point will mark the number of cubic feet of gas made during every hour of the 24. If the production of gas is regular, the figures formed by the pencil will be regular also; if, on the contrary, any neglect has occurred, the irregularity of the figure will detect it, and point out the hour and the amount of difference; because, if the speed of the revolving disc be decreased, the figure formed will approach nearer to the straight line; if increased, the points of intersection upon the divided circle will be further apart. The case of the station-meter is usually much ornamented, and has a Latin inscription.

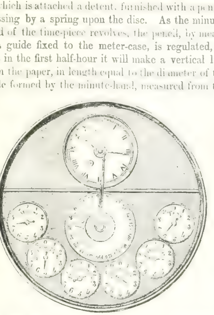

Fig. 1027. TELL-TALE ATTACHED TO THE STATION-METER.

The gas is next passed into the *gasometers*, or gas-holders, which form such conspicuous objects at gas-works. Each gas-holder is a cylinder, closed at the top, and floating, or suspended, with its open end in a cistern of water. The dimensions of the gas-holder are regulated by the geometrical law, that a cylinder has the greatest capacity with a given surface, when its height is equal to half its diameter; hence the capacity of the gas-holder is such, that when raised to its highest point in the water, its height is equal to the radius of the base. It is usual, however, to increase this height by one or two feet, to prevent the possibility of the gas escaping from its under edge when raised to the greatest height in the water. For example, a gas-holder of the capacity of 30,000 cubic feet, has a diameter of 42 feet, and a height of 23. This was long considered to be the largest that could be conveniently made; but the Westminster Gas-works are provided with 18 large gasometers, of which the largest is 95 feet in diameter, 40 feet high, and of the capacity of 250,000 cubic feet; and at the present time telescope gasometers 160 feet in diameter are in use. The necessity for such abundant stowage will be apparent from the fact, that at these works a million and a half cubic feet of gas are produced every 24 hours during the winter months These gas-holders are formed of sheet-iron plates, riveted together, and coated with tar on both sides, which makes the joints gas-tight When the gas-holder is of large size, it is strengthened within with cross iron rods, and the top is supported by rods stretching obliquely down to the sides; the under edge is strengthened by curved cast iron bars, bolted together, to which the oblique rods are attached. A number of rings at the top are connected to the upper ends of the supporting rods, and serve to suspend the gas-holder by a chain, which, passing over a pulley attached to a strong outer frame, has a counterpoise weight W, Fig. 1022, at the other end.

A common method of mounting gas-holders is shown in Fig. 1022. The gas-holder G dips into a tank of water T, rising above the surface of which are two pipes, one of which brings in the gas from the station meter, and the other conveys it to the main for distribution. With large gasometers this great body of water is an inconvenience, especially in frosty weather, when, to prevent freezing, steam must be introduced. Hence the arrangement shown in Figs. 1028, 1029, is to be preferred. In this a central core of masonry, brickwork, or sheet-iron, takes the place of the great body of water, and the only water required is that in the ring-shaped space surrounding the core. In the centre of this core are two channels for the two pipes *a* and *b*, by one of which the gas enters the gas-holder, and by the other it escapes into the street mains. The gas-holder, if small, is suspended from its centre by a chain, as in Fig. 1022, and to the pillars of the triangular or polygonal cast-iron frame guiding-rollers are attached, to keep the cylinder horizontal, and enable it to move easily.

By this method of suspension with the chain and counterpoise, the greater part of the weight of the gas-holder is taken off, and only so much left as is necessary to expel the gas. This weight must, however, vary in proportion to the sinking of the gasometer; it must lose a portion of its weight equal to that of the water displaced by the submerged portion; and hence the pressure of the gasometer on the contained gas would vary according to its depth were it not for an ingenious contrivance. The chain which bears the counterpoise is so adjusted as to equal one-half the weight which the gas-holder loses by immersion: the weight lost by the gas-holder in sinking is replaced by a portion of the chain coming over the pulley and balancing an equal portion of the chain on the other side, which is the same thing as adding one-half of this portion to the side of the gasometer. By a nice adjustment of weight and bulk, very large gas-holders have been constructed without chains or weights, the buoyancy of the gas serving in all positions instead of a counterweight. The pressure to which the gas is subjected is generally such as will sustain a column of from 1 to 2 inches of water.[1]

The large amount of space required for the above description of gasometer, has led to the invention of what is called the *telescope gasometer*, which, with the same diameter, will accommodate a larger volume of gas without increasing the area of the ground. This gasometer, shown full and empty in Figs. 1028, 1029, consists of 2, 3, or more concentric cylinders, the bottoms and tops of which, except the uppermost, are furnished with flanges turned in opposite directions; the flange turning outwards and upwards at the bottom, and inwards and downwards at the top. The uppermost cylinder is covered at the top, but the others are open both at top and bottom. Now, supposing the cylinders to be all sunk in the cistern, and gas to be introduced, the innermost cylinder will rise first, and when its bottom reaches nearly to the surface of the water, its curved flange catches the flange of the next cylinder, which also rises; and when this has advanced sufficiently high it lifts the next. The escape of the gas, and the admission of air, are prevented by the lower flange of each cylinder taking up a quantity of water, which acts as a *water lute*. These gasometers are usually suspended at three points in their circumference, by means of three chains running over pulleys attached to three pairs of pillars. The larger ones, not telescopic, have commonly 8 or 12 such supports, and being decorated in the style of ancient amphitheatres, are often imposing in appearance.

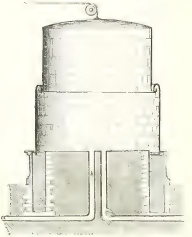

Fig. 1028. TELESCOPE GASOMETER, FULL.

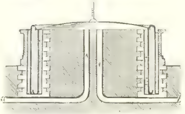

Fig. 1029. TELESCOPE GASOMETER, EMPTY.

The gas is distributed to the streets and houses of the town or district by means of cast-iron pipes, 9 or 10 feet long, cast with a turned up margin or shoulder at one end, and a mouth-piece at the other, as in Fig. 1031. When placed together, the space between them is filled up with greased tow and leaded all round, so as to be perfectly air-tight.[2] The smaller pipes for the supply of houses are often drawn leaden or pewter tubes, but they ought to be of iron; for if a leak in the pewter pipes take fire, the surrounding metal will melt, and the hole enlarge until the flame becomes dangerous. The supply of gas to the mains is a matter of importance, not only as regards the convenience of the consumer, but the economy and consequent success of the works. In the dark evenings of winter the mains must be kept well filled with gas under a certain pressure; when the shops are closed this pressure must be moderated, so as to suit the diminished consumption, and yet be sufficient to keep the street lamps and the lights of private houses burning; towards sunrise this pressure must be diminished, and at a certain hour, varying with the season, cease altogether. Thus it will be seen that the pressure is a constantly varying quantity, which requires nice attention on the part of the superintendent.

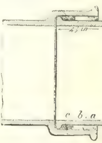

Fig. 1031.

One of the metropolitan districts supplied by a single gas company, is divided into a number of sub-

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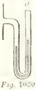

Fig. 1030.

(1) The gauge attached to various forms of apparatus in the gas-works for ascertaining the pressure of the gas, is a bent graduated glass tube, containing water or mercury, open at one end, and with the other end screwed into the vessel containing the gas. Thus, if the end *b* of the tube, Fig. 1030, be screwed into a vessel containing gas of the same pressure as the external air, the liquid will be of the same height in the two limbs of the gauge. If the pressure of the gas be greater than that of the external air, the liquid will rise in the tube *a*, and the pressure of the gas will be 1, 2, or more inches, according to the height to which the liquid rises. If, on the contrary, the pressure of the gas be less than that of the outer air, the atmospheric pressure, always acting at the open end *a* of the tube, will prevail, and the liquid will rise in the limb *b*.

(2) According to Mr. Clegg, lead joints are not to be depended on. His directions for making a joint are as follows:—"Caulk into the bottom of the socket, to the depth of about 2 inches, white rope yarn, well covered with putty; then, at the lip of the socket, caulk in tarred gaskets of such a thickness that it will just fit into the annular space left between the pipe and the socket, and to such a depth that a space of about 1½ inch will be left between the two yarns all round the pipe. At the top of the socket, where the ends of the tar-gaskets meet, draw up a portion to form a *gate*, exactly in the same way as for running a lead joint. Take 2 parts of melted Russian tallow, and 1 part of common vegetable oil, and pour the mixture, while warm, into the *gate*; it will run into and fill up the space between the two yarns. As the mixture does not contract in cooling, and is quite impervious to the air, it must form an air-tight joint. *a*, Fig. 1031, is the tarred rope-yarn, *b* the tallow and oil, and *c* the puttied white yarn.

districts, each of which consumes a variable quantity of gas, some more and some less. A division containing numerous shops will consume more than one consisting chiefly of private houses; so that the pressure for the one requires to be greater than that for the other. The Westminster district, for example, has about 20 such divisions, comprising nearly 150 miles of main, and the varying pressures required by each division are managed in the following manner:—

In the superintendent's room is a number of small gasometers, called *pressure indicators*, and painted over each is the name of the sub-district intended to be supplied. Each gasometer, A, Fig. 1032, is about 12 inches in diameter; it is supported in a tank of water in such a manner that it can rise and fall according to the pressure in the mains, with which it is connected by means of the small pipe B. To the upper part of each gasometer is attached a vertical rod C, carrying a black lead pencil, which is made to bear upon a cylinder D, covered with a sheet of paper along the top of which are marked the 24 hours of the day. From these hours perpendicular lines are drawn to the bottom of the sheet: the paper is also ruled horizontally, and marked from the bottom, showing tenths. By connecting the cylinder with a time-piece, it is made to rotate on its axis, by which means the pencil draws a line opposite the hour when it is set going. If the pressure be constant for a number of hours, this line will of course be a circle, or a portion thereof, round the cylinder, parallel with the top and bottom edges of the paper, or a straight line when the paper is unrolled; if the pressure vary, the line will be diagonal or zigzag. At the end of 24 hours the paper is taken off the cylinder and a new one added. All these papers are preserved in portfolios, each one for its own division, so that the Company has a permanent record of the care and attention of the superintendent, an accurate referee in case of complaints from customers of insufficient supply, and an index of the gaseous wants of the district, or of any one of its divisions, to which light is dispensed.

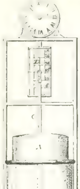

Fig. 1032.

In smaller works, where the district is supplied with gas without such a system of subdivision, the pressure is regulated by an apparatus called the *governor*. This is a self-acting instrument, and regulates the supply according to the demand. The governor consists of a cast-iron tank, *a a*, Fig. 1033, containing water, in which the regulating vessel *b b* floats; *c* is a cone of cast-iron, suspended by an eyebolt to the top of the floating vessel; *d* is the pipe by which the gas enters; on the top of this pipe is a plate *i* furnished with an aperture which fits the diameter of the cone at the base, forming what is called a *throttle-valve*, so that if this were raised to its full height it would completely shut off the gas, and prevent it from entering the vessel; *e* is the outlet pipe, by which the gas escapes to the street mains. By adjusting the counterbalance *f* an increase or decrease of pressure may be produced. The outlet pipe *e* communicates with the mains, and the inlet pipe *d* with one of the gasometers of the works. Now it will be evident, that if the density of the gas in the inlet pipe becomes by any means increased, a larger quantity of gas must pass between the sides of the adjusting cone and the aperture in the plate *i*, the consequence of which will be, that the floating vessel *b b* will rise, and thereby contract the area of the opening in *i*; if, on the contrary, the gas in the inlet pipe decrease in density, the vessel will descend, and thus enlarge the opening *i*; so that whatever density the gas may at any time assume in the Company's gasometers or mains, its pressure in the floating vessel will be uniform, and, consequently, the velocity of the gas passing into the mains will be regular: for, when the aperture of the plate *i* would admit more gas than necessary for the supply to the mains, the floating vessel rises, and diminishes the orifice of the inlet pipe; and when, on the contrary, the inlet does not allow a sufficient quantity of gas to come from the gasometers, the gas passes out of the governor into the mains, and, in so doing, the vessel descends, and increases the orifice of the inlet pipe to admit more gas into the mains. A more compact arrangement of the above has lately been registered, under the title of "Glover's gas-light economic regulator."

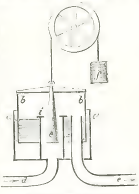

Fig. 1033. THE GOVERNOR.

The water gas-meter, by which the consumer registers his consumption, may be thus illustrated:—When a number of vessels of a known capacity, such as one cubic foot each, are arranged round a central axis in such a manner that, without any loss of gas, one after the other shall be filled with the gas in revolving, and for this purpose are inverted in water, it follows that just as many cubic feet of gas will have passed as there are vessels that have been filled. Suppose there are four such vessels: as each in succession fills and rises, the axis will be turned once round, thereby indicating the passage of four cubic feet of gas. In the gas-meter shown in section, Fig. 1034, instead of

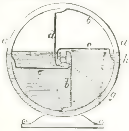

Fig. 1034.

four separate vessels, there is within an outer case *a a* more than half filled with water, a drum *b* moving round on two pivots, and divided into four compartments, *b*, *c*, *d*, *e*, by as many bent partitions, but enclosed at front and back by straight sides. The partitions are bent round, so as to form a central space *g*, and thus the gas can pass from one division into the next, and also escape into the outer case *a a* by slits in the rim of the drum. The gas enters at the back of the outer case by a pipe, which proceeds into the central space, where it turns up, and rises a little above the level of the water. One of the pivots on which the drum works is fixed in the bend of this tube. A peg on one of the straight sides at the back is the other pivot, and carries a toothed wheel. As one partition gets filled with gas, it becomes lighter, and rises, thereby causing the drum to perform a portion of a revolution. In Fig. 1034, the pipe *g* is pouring gas into the division in the direction of the arrow. As the gas accumulates in it, it gradually lifts this division out of the water, and brings the compartment *b c* into the same position. As this gets filled, and ascends, the compartment *d* comes round; then *c b*, which, being filled, and rising, completes one whole revolution. Now it will be seen, that as each compartment rises above the level of the water, the gas contained in it passes out through the slit into the outer case, and from that along a tube at the top of the case for supplying the burner. Thus, while one partition is rising, another is being brought under the water; and while the one is parting with its gas, the other is being filled, and so on. The toothed wheel gives motion to a train of wheels, adjusted so as to represent, by means of hands moving round dial plates, the units, tens, hundreds, and thousands of revolutions of the drum, by which means, the quantity of gas passed through the meter can be read off in cubic feet. All this may be further illustrated by Figs. 1035, 1036. In Fig. 1036, the direction of the gas is marked by arrows. The box *a*, in which the inlet valve is contained, is soldered tight, having no communication with the rest of the case, except through the valve, the position of which is shown by the arrows: *b* is the inlet pipe projecting above the water line, conveying the gas into the meter by the bent arm *c*, Fig. 1035, rising above the water between the convex cover and the inlet hoods. *d* is a float attached to the inlet valve, adjusted so that when the water falls below the centre opening, the valve will close, and the gas cease to enter the meter. Motion is communicated to the train of wheel-work behind the index from a spiral worm *w*, Fig. 1036, fixed on to the axis of the drum working into a wheel, the spindle of which passes through the tube *t*, sealed by dipping under the water contained in the case.

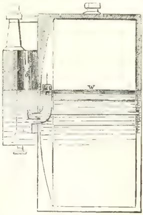

Fig. 1035.

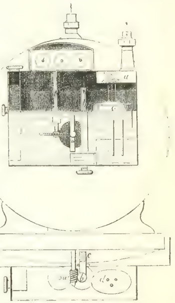

Fig. 1036. WATER GAS-METER.

This form of meter is not free from objections. The water is liable to freeze in cold weather, whereby the passage of the gas is completely stopped. Mr. Lowe has proposed the use of a solution of caustic potash or soda, which is not readily affected by frost, to replace the water in the meter: this would also tend to render the gas more pure, should either carbonic acid or sulphuretted hydrogen have escaped the purifiers at the works. Another objection is, that if the water-level be lowered, so that the same compartment may communicate at once with the central and outer spaces *g* and *a a*, Fig. 1034, more gas will pass than can be registered. Or if the meter be tilted forwards, the gas will pass without being registered at all. By this means, the Company is liable to fraud on the part of dishonest persons. Other meters have been invented which have not these objections, such as the *dry gas-meter*, in which the measuring chambers are separated from each other by flexible partitions of leather.

In the dry meter the gas is measured by the number of times that a certain bulk will fill a chamber capable of undergoing contraction and expansion by the passage of the gas. These alternate contractions and expansions of the chamber give motion to certain valves and arms of simple construction, which, by the aid of a few wheels, are made to turn the hand of a dial, as in the wet meter. In Defries's meter there are 3 measuring chambers, separated from each other by flexible partitions of leather, partially protected by metal plates. The pressure of the gas, expanding the flexible partitions, makes them assume the form of a cone on either side, the motion of which backwards and forwards on both sides sets the measuring machinery in motion. By an action somewhat similar to that of a three-throw pump, a continuous stream of gas is forced out of the machine, it having been found that with only two flexible partitions the lights were liable to oscillation.

The constant bending of the leather backwards and forwards soon causes this meter to get out of order; and it may even happen that one partition may give way without its being discovered, so that a customer burning a large quantity of gas would have only a small quantity registered. Various devices have been attempted, and many patents taken out, to remedy the evil and to produce a dry meter free from objection. As far as we have been able to judge, the meter by Messrs. Croll and Glover is the most successful. In this meter, leather is indeed used, but merely to form a flexible band, which does not take any part in the measuring. The external form of the meter is that of an oblong box of iron plate or galvanised iron. Fig. 1037 is a front, Fig. 1038 a side-view, and Fig. 1039 shows the connexion between the measuring apparatus and the index, as seen in looking down upon the top of the meter. In the meter itself the interior is not visible, but in our figures we have supposed the sides to be of glass, instead of sheet-iron, for the purpose of showing the interior arrangements. The interior consists of two short cylinders closed at one end, and separated from each other by the plate P, Fig. 1038, and closed at the other ends by the discs A A. Now these cylinders may be compared to a steam-engine with two cylinders placed in opposite directions, in which, while the piston is descending in one it is ascending in the other, and *vice versa*; with this difference, however, that instead of pistons working in cylinders, the disc end of each cylinder works backwards and forwards; for which purpose each disc is attached to the partition P by means of leather joints, L L, which act as hinges, and allow each disc, A, to move in towards P, and force out the gas contained in it, or to recede from P while it is swelling out under a fresh supply. Now the comparison with the steam-engine will be more evident if we consider that, while one drum is being filled the disc of that drum is expelling the gas on the other side to supply the burners, and the other cylinder and disc are alternately performing the same functions. The discs A A, therefore, act the part of pistons, and by their motion to and fro afford the means of measurement: they are kept in place by a hinge joint, *s*, attached to the upright rods R R. E E are parallel motions attached to each disc and to the top plate of the meter. The band of leather, L, as already mentioned, does not assist in measuring the gas, so that its contraction or expansion only decreases, or increases the capacity of the hinge, the disc being still at liberty to move through the required space only. The leather is so attached that it can bend only in one direction, which renders it much more durable than in Defries's meter. Now, as the gas passes into the enclosed space, and by its equal pressure distends the drum, the disc A is kept parallel with the partition P by the arrangement of levers, E *y*, E *y*, and *x*. This parallel motion also causes the rods R, one of which is situated on each side of the meter, to move each through the

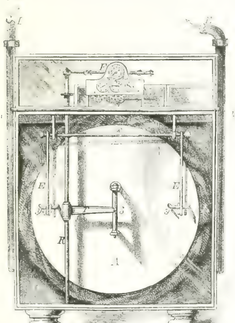

Fig. 1037. CROLL AND GLOVER'S DRY METER.

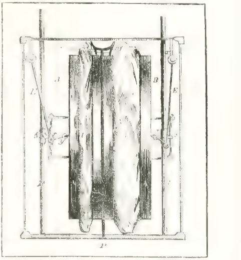

Fig. 1038. SIDE ELEVATION.

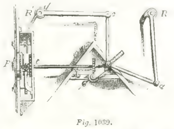

Fig. 1039.

half of a circle, by means of the jointed levers, *s r*, attached to them. At the top of these rods are two arms, R′ *d c* and R *a*, Fig. 1039, each of which, participating in the motion of the rods R R, describes alternately the arc of a circle. A rotatory motion is obtained by means of two connecting rods, *a b*, *c b*, Fig. 1039, attached to these arms, and also fitted to two other arms which work two D valves, D D, sliding backwards and forwards over three apertures, 1, 2, 3, Fig. 1040; of which apertures, Nos. 1 and 3 lead to the inside and outside of the cylinders respectively, and No. 2 to the exit pipe E, Fig. 1037. Now it is the duty of these valves to regulate the flow of gas into and out of the two chambers of each division of the instrument; or, to return to the comparison of the steam-engine cylinders, to admit steam or gas to the cylinders above and below the pistons. In the case before us the gas is made to flow into the cylinder to distend it, and in doing so, expels the gas on the other side of its disc to the outlet E in connexion with the burners. This being done, the valve is immediately reversed, and gas enters on the side of the disc from whence it was last expelled. This process is alternately performed by the other disc. The equal and continuous flow of gas is obtained by the two valves, D D, being placed at right angles to the double-cranked shaft, and the two cranks on the shaft being at an angle of 45° to each other. By this arrangement, in proportion as the one valve closes, the other opens: but the closed valve always begins to open before the other is quite shut.

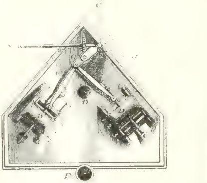

Fig. 1040

Let us now trace the course of the gas in its passage through the meter. But first it must be clearly understood, that the force which sets in motion the various parts of the meter is the gas itself, which is placed under pressure at the gas-works, as already explained, in order that it may be driven in a continuous stream along the mains, through the meters, and up to the burners of the consumers. That this pressure is amply sufficient for the purpose, will be evident, when it is considered that the pressure of only half-an-inch of water, multiplied into the area of the disc A, Fig. 1037, which, in a ten-light meter, is 10 inches in diameter, will amount to many pounds. Now, suppose a continuous stream of gas under pressure to be passing down the inlet pipe I, Fig. 1037. It proceeds as far as *i*,[1] at which point it meets with a horizontal tube which conducts it into the triangular chamber, Fig. 1040, by the hole o. Then passing down the open slit No. 1, Fig. 1040, it enters into one of the cylinders, distends it, and forces the gas which was on the outside of the disc to escape through No. 2 along a tube conducting to the exit pipe E, Fig. 1040, or E, Fig. 1037; this tube being on the level of *k*, Fig. 1037. Now, while this action is going on—while the cylinder on one side is being distended—that on the other is already full, the gas is shut off from it, and made to pass on the outside, where, exerting its pressure on the disc A, Fig. 1037, it forces it inwards, and the gas escapes along a short pipe attached to either side of the partition P into No. 2 of Fig. 1040, and so escapes to E. In Fig. 1041, the direction of the gas is marked by the arrows: it is passing from o, Fig. 1040, down the aperture 1, Figs. 1040 and 1041, which leads to the inside of the cylinder. From this it is pressed through No. 3 into No. 2, and so to the burner.

The triangular chamber, Fig. 1040, and D, Fig. 1037, has no connexion with the cylinders, &c. below it, except through the tubes already indicated; and the train of wheels, F, Fig. 1037, is also so boxed in as not to be exposed to the corroding action of the gas. The rods R R pass into this upper compartment through leathern washers and a stuffing of Berlin wool.

The circular motion of the double crank is transmitted by means of an endless screw and a spur-wheel, Figs. 1039 and 1041, along a wire *e*, Fig. 1039, to a simple train of wheels, which record their revolutions on the face of the dial F. This dial, Fig. 1042, consists of hands moving round circles which register the number of cubic feet of gas consumed, in units, tens, hundreds, thousands, &c. The top circle registers units: the right-hand circle hundreds; that is, the motion of the hand from 0 to 1 shows that 100 cubic feet of gas have passed through the meter; and, of course, a complete revolution of this hand indicates ten times that quantity, or 1,000 cubic feet. So the motion of the hand of the centre circle from 0 to 1 indicates 1,000 feet; and a complete revolution 10,000 feet. The motion of the hand from 0 to 1 of the left-hand circle indicates 10,000, and a complete revolution 100,000 cubic feet. Now, in reading off the numbers on the circles, we must take the number at which the hand is pointing, or the *lower* of the two numbers that the hand may happen to be between. If, for example, the

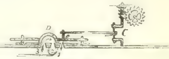

Fig. 1041

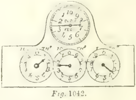

Fig. 1042.

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[1] The pipe is extended considerably lower, as seen in Fig. 1037, in order to catch any deposit of moisture or impurity and thus prevent it from entering the meter

hand be anywhere between 5 and 6, on any one of the circles, 5 is to be taken. Commencing, then, at the left hand, the hand is between 1 and 2: write down

10,000
2,000 for the middle circle,
300 for the right-hand circle.

12,300

Now, suppose that in taking the register three months before, the quantity had been set down as 9,100; then, subtracting this from 12,300 gives 3,200 cubic feet of gas as the consumption for three months.

The top or units dial is not used in registering: its use is to indicate to the collector, and also to the consumer that the meter is acting properly; for they could not, of course, wait while 100 feet were being registered.

The profitable consumption of gas, whereby the greatest quantity of light is obtained at the least expenditure of gas, depends, in great measure, upon the form of the burner, and the mode by which the flame is supplied with the air necessary for its combustion. Such arrangements must be made as will ensure the complete combustion of the gas; that is, there must be a sufficient supply of oxygen to convert the carbon of the gas into carbonic acid, and the hydrogen of the gas into water. If the supply of oxygen be deficient, the flame will be smoky from excess of carbon, and much light will be lost.[1] In such a case, the obvious remedy is, either to diminish the supply of gas, or increase the supply of air. This may be done by modifying the form of the gas-burner, or of its glass chimney. With respect to the form of the burner, it has been found by experiment that a plain jet $\frac{1}{4}$ inch in diameter at the orifice, will not give a flame free from smoke of a greater height than $2\frac{1}{2}$ inches; but the same quantity of gas which would give a smoky flame from a plain jet, will burn with a clear bright flame by extending or dividing the aperture of the jet, so as to expose a larger surface of flame to the air. It is not, however, necessary to increase the size or superficial area of the flame. It may even be diminished with increased luminous effect, by having two small apertures instead of one large one, by making them follow an oblique direction, so that the jets may cross each other. This forms the *fish-tail* flame. By having three apertures, we get what is called the *cock-spur*, Fig. 1043. The light may be still further improved by making a number of small apertures so near, that all the jets unite laterally into one, as in the *union* jet, Fig. 1044. Instead of these methods of improving on the single round jet, there may be a slit across the top of the beak, so as to give a sheet of flame, as in the *bat-wing* jet, the *swallow-tail*, and *fan* jets, Fig. 1045. In the Argand burner,

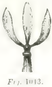
Fig. 1043.

Fig. 1044.

Fig. 1045.

a circle of small holes of equal size supplies the gas, and a current of air is admitted through the centre of the flame.[2] With such an arrangement, there is a larger amount of combustion, and consequently a higher temperature than in the plain jet; but with the same consumption of gas, the Argand burner does not give so much light as the flat flames of the fish-tail and bat-wing burners. An Argand burner, which consumes $1\frac{1}{2}$ cubic feet of gas per hour, affords light equal to that of 1 candle; an Argand consuming 2 cubic feet per hour, is equal to 4 candles; and when the consumption is 3 cubic feet per hour, it is equal to 10 candles. [See PHOTOMETER—LAMP.] In this experiment, however, the quality of the gas is not stated.

The construction of the chimney has an important influence on the proportion of air brought into contact with the surface of the flame. An unsteady smoky flame immediately becomes converted into a bright brilliant one, by putting over it the glass chimney; for by this means the quantity of air or draught is increased. But the form and dimensions of the chimney are important to be considered. A short, wide, cylindrical chimney scarcely increases or diminishes the proportion of air. Its advantage is to steady the flame; but if the chimney be moderately tall and narrow, or contracted towards the top, as in Fig. 1046, or suddenly contracted near the bottom, as in Fig. 1047, the draught becomes greatly increased, and the light improved. The supply of air to the flame may, however, be too abundant, so that instead of assisting combustion, it may, by cooling the flame, interfere therewith. Such is often the case with the cylindrical chimney, and it was remedied soon after Ami Argand's invention in 1789, [see ARGAND LAMP,] by contracting the diameter of the glass chimney at a certain height above the burner, so as to form a shoulder a few lines in width, as in Fig. 1048. The draught, as it enters the cylinder, has its direction changed at the shoulder, and is thus thrown upon the flame at a certain angle. By this contrivance the supply of air is diminished, but it acts in a more advan-

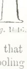
Fig. 1046.

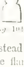
Fig. 1047.

Fig. 1048

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[1] It appears from the experiments of Dr. Henry, that those substances which give most light in burning, produce the most brilliantly illuminating gas when distilled, and that the illuminating power of a gas is proportionate to the quantity of oxygen required to consume it. Thus the illuminating powers of the following gases increase with the quantity of oxygen required for the combustion:—

100 measures of	hydrogen	require 50	measures of oxygen.
,,	Dried peat gas ...	68	,,
,,	Oak wood gas ...	54	,,
,,	Cannel coal gas	170	,,
,,	Lamp oil gas ...	190	,,
,,	Wax gas	220	,,
,,	Pure olefiant gas	284	,,

(2) In the original Bude-light proposed by Gurney, oxygen gas instead of air was passed through the flame, whereby its brilliancy was greatly improved. The present Bude-light is a gas flame with two, three, or more concentric burners with chimneys supplied with common air, and a reflecting apparatus of peculiar construction.

tageous direction, and instead of cooling the flame, assists the combustion, and increases the illuminating power. We are not sure but that the best form of chimney remains to be discovered.

In the use of gas-lights within doors, some provision ought to be made for ventilation. One part by weight of good coal-gas produces nearly three parts by weight, or about its own bulk, of carbonic acid gas, which, in moderate quantities, is fatal to animal life, and in crowded rooms and assemblies, where ventilation is not attended to, produces head-ache, fainting, palpitation, and other distressing symptoms. But in addition to carbonic acid, sulphurous acid is one of the results of the combustion of coal-gas, owing to the presence of certain sulphurous compounds which the purification of the gas does not wholly remove. This sulphurous acid, in contact with the air, becomes converted into sulphuric acid, the corrosive action of which is exerted on the walls and furniture, books, pictures, &c. The hydrogen of the gas produces water during the combustion, and this often serves as a vehicle for conveying some of the other products of combustion.

With the view of getting rid of these noxious vapours, there is sometimes suspended above the chimney a bell-shaped vessel, from the upper part of which proceeds a narrow tube, leading out of the apartment. By this means the vapours are carried away, more or less perfectly; but if the tube be of great length, the contents get cold and cease to be carried off; so that the ventilation stops, and the vapours get diffused over the room. The water produced by the hydrogen may even become condensed, and, flowing back along the tube, extinguish the flame. By a contrivance of Dr. Faraday, the bell-vessel is rejected, and a copper tube, of about the same diameter as that of the flame, conducted from its summit out of the apartment: this tube becoming heated, a rapid current is established, and the products of combustion effectually carried away. By another contrivance of the same distinguished philosopher, the ventilating current is made to descend between two concentric glass chimneys, of unequal height, the lower one being the interior, and the upper one covered with a disc of talc. When the current has reached the bottom, it passes away by a ventilating tube bending upwards. The descending current is established by applying heat to the bend of the ventilating tube, where it begins to ascend; and when this current is fully established the gas is lighted, and the exterior or higher of the two chimneys is covered with the plate of mica. The burner is supplied with air in the ordinary way, and the products of combustion are carried from the top of the inner chimney down through the space between that and the exterior chimney into a box, in which terminates the ventilating pipe for conveying the vapours outside. A globe of ground glass, open only at bottom, is placed over the lamp. It is stated that, notwithstanding the two glass chimneys, a greater amount of light is obtained by this arrangement, and certainly a larger flame, than with the ordinary Argand burner.

In the manufacture of gas there are certain secondary products which remain to be accounted for. A ton of coals, weighing on an average 2,240lbs., yields—

1 chaldron of coke . . . . =	1,494lbs.
12 gallons of tar . . . . . =	135 „
10 gallons of ammoniacal liquor =	100 „
9,500 cubic feet of gas[1] . . . . =	291 „
Loss . . . . =	220 „
	2,240 lbs.

The coal, in the process of distillation, increases in bulk about 28 per cent. On an average, about two bushels of coke are obtained from a cwt. of coals, or about 66 per cent. of the original weight of coal. About 25 per cent. of the coke is used as fuel for heating the retorts, and the remainder is sold.

The tar and ammoniacal liquor or gas water are collected in the tar cistern, in which the tar occupies the lowest position. The ammoniacal liquor is used in the manufacture of sal ammoniac and carbonate of ammonia. The tar is used in the manufacture of patent fuel and of kreosote, and as a paint for palings, &c.; and in some gas-works it is used with the coke fuel for heating the retorts. By distillation, 100lbs. of the tar yield about 26lbs. of an oily liquid, known as *coal oil;* the light product which first distils over is *coal naphtha.* Pitch remains behind; and this is used largely for paying wooden piles, &c., and the bottoms of ships. It is cheaper than the pitch of wood-tar, but not of so good a quality. Coal naphtha is used extensively for dissolving caoutchouc, and also for burning in the naphtha lamp. By impregnating coal-gas with its vapour, the illuminating power of the gas is greatly increased. It was originally proposed by Mr. Lowe to fill the ordinary wet gas-meter, Fig. 1036, at the house of the consumer, with purified naphtha, which was to be kept filled to the same height from a reservoir in connexion with it, and thus the gas was to be measured and saturated with naphtha at the same time; or the gas might be passed through an ornamental vase situated between the meter and the burner. Other applications of gas-tar will be noticed in the APPENDIX.

It was calculated in 1852 that the annual consumption of gas in London and the environs amounted to not less than 4,000 millions of cubic feet, the light produced by the combustion of which would be equal to that of 213 millions of pounds of tallow candles. The consumption at the present time is doubtless much increased. In the year 1852 the annual consumption of coal by the London gas companies was 408,000 tons. Above 900 tons per day were consumed in foggy weather in winter. From 1827 to 1839 the quantity of gas consumed in the Metropolis doubled what it had been from 1822 to 1827; and from 1837 to 1848 it again doubled what it was in the preceding ten years. [See APPENDIX.]

According to a rough estimate, 350,000 tons of coal would produce nine times that sum in cubic feet

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(1) One cubic foot of coal-gas weighs 214½ grains.

as the annual supply of gas to the metropolis, of which the leakage and loss may be estimated at 20 per cent. The street-lamps are reckoned to burn 4,000 hours per annum, and generally consume 5 feet per hour. A glance at the gas-share list in the *Journal of Gas-lighting*, published every month, will show the enormous extension of this art throughout Great Britain and Ireland; and it will also be seen that many of the continental cities are lighted by British companies, of which there are about a thousand.

[The following account of the application of the refuse products of the Edinburgh Gas Works was written for the first edition of this work by the late Dr. George Wilson, Professor of Technology in the University of Edinburgh.]

The Edinburgh Gas-works are situated in the valley of the Canongate, which runs from west to east towards the sea, parallel to the High-street, and the North British Railway. The chemical works, where the products of the gas-works are turned to account, are distant about two miles from the latter, and the gas-works are at a lower level. The Calton Hill is interposed between the two manufactories; and at a former period the gas liquor was carted in barrels to Bonnington on the Water of Leith, where the chemical works are situated. Recently, however, the gas liquor has been lifted over the shoulder of the Calton Hill by an ingenious force-pump, and the difference of level is then sufficient to carry the liquor to Bonnington, which though higher than the Canongate is lower than the Calton Hill.

The liquor separates into two strata; the lower and heavier being TAR; the upper and lighter, an impure aqueous solution of carbonate and hydrosulphuret of ammonia; this is called the *ammoniacal liquor*. It is the less valuable of the two liquids, and is treated as follows:—To separate it from a portion of tar which always accompanies it, it is subjected to distillation. The distilled liquid is in greater part converted into sal ammoniac, but a considerable quantity is also manufactured into sulphate of ammonia.

The first step in the sal ammoniac process is, the neutralization of the distilled liquor with hydrochloric acid, which as well as sulphuric acid is made at the works. The neutralised solution is then pumped into large caldrons, where it is concentrated till it has reached the crystallising point. It is then drawn off into large vats or troughs, where as it cools it deposits multitudes of small feathery crystals, consisting of rows of minute octohedrons or allied forms attached to each other. In cold weather beautiful large cubes of sal ammoniac are sometimes produced.

The feathery crystals are transferred from the troughs to a drying apparatus, consisting of a shallow oblong open box, made of stone, and heated by a furnace below. The dried salt, in a state of granulation resembling brown sugar or salt, is then mixed with charcoal-powder, which is intended to reduce any oxide of iron present, so as to prevent a brown colour being given to the sal ammoniac when raised in vapour. The salt after this treatment is subjected to sublimation. The subliming vessels are shaped exactly like a man's hat, arranged in the furnace with the crown downwards. They are some three feet in depth, and two and a half in diameter. When charged with salt they contain a quantity of material sufficient to demand a week's unceasing application of heat for its sublimation. Each pot is covered by a leaden dome or cupola, which is luted on with clay, and has an aperture in the centre through which the salt is allowed to sublime away, for some period after the commencement of the process. This occasions a considerable loss of material, but no other way is known of securing a hard, coherent sublimate. There seems reason to believe that the presence of moisture in the imperfectly dried salt, is the cause of its condensing at the commencement of the process as a spongy mass. At all events a firm cake does not form till after some time. The workmen proceed empirically, and when they judge that a sufficient interval has elapsed, they close the central aperture in the leaden dome by a plug of clay, and the sublimation continues for a week. The hemispherical cakes of sal ammoniac thus produced, are rasped on their outer surfaces to remove any crust or colouring matter, and broken into wedges, which are packed in barrels and sent all over the world.[1]

Sulphate of ammonia is largely purchased by farmers in spring, and is used by the alum makers for their ammonia alum.

In preparing it, the distilled ammoniacal liquor is saturated with sulphuric acid, and then "*salted down*," *i. e.* concentrated till the hot solution precipitates small crystals. These are removed by colanders or perforated ladles, dried, and packed in barrels lined with paper. The sulphate of ammonia thus prepared, is believed to contain only one atom (*i. e.* the minimum quantity) of water of crystallisation.

The tar containing much water is transferred to a still heated by a naked fire, and sometimes, also, to a still through which steam is blown. In either case crude naphtha and the vapour of water distil over together, and are separated by their different densities. The naphtha is then digested with oil of vitriol in a leaden trough. Ammonia and various other substances are removed by this treatment, the *rationale* of which is but imperfectly understood. Quicklime is then added to remove the acid, after the naphtha has been washed with water, and the naphtha is distilled again. It is then ready for the market.

The tar from which the naphtha has been separated is transferred to another still, and heated by a naked flame to a much higher temperature than that applied to the crude tar accompanied by water in the first distillation. A less volatile liquid than naphtha is now yielded, which is termed pitch-oil, and has been largely used to impregnate wood so as to preserve it from the attacks of insects and from decay.

What is left in the still is run out hot. It hardens

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(1) The Edinburgh sal ammoniac is sent to New York on the one hand, and to Petersburgh on the other. In Russia, sal ammoniac is used by the common people occasionally as a condiment, in preference to culinary salt. If the saliva be at all alkaline, as it often is, it liberates ammonia from the sal ammoniac, and occasions a peculiar and not very pleasant impression on the organs of taste.

into a soft solid, which in cold weather exhibits, when broken, the most perfect specimens imaginable of conchoidal fracture on the largest scale. No market at present exists for this pitch. It is used at the works to a small extent as fuel; and in districts where coal or wood are dear it would be of great value, could it be cheaply transported. If distilled at a red heat or thereabouts, it yields a third volatile liquid and coke.

At present no market, or almost none, can be found for the tar, which was formerly largely consumed at the sea-ports, and was sent up the Baltic and elsewhere. The multiplication of gas-works, however, on the continent, and the absence of duty on foreign as distinguished from British tar, has greatly lessened the sale of the latter abroad.

At Bonnington they also make sulphurous acid from oil of vitriol and vegetable matter (shellings). The acid is employed to saturate carbonate of soda: the resulting sulphite being sold to the paper makers, who employ it, under the name of *antichlore*, to remove the last traces of chloride of lime from the rags which have been subjected to the bleaching process.

Oil and Resin Gas. In places where coal is difficult to procure, oil may be used in the manufacture of gas: the crudest oil, even pilchard dregs and the sediment of whale oil, are applicable to the purpose, and the process of manufacture is much more simple than in the case of coal; all that is necessary being to raise a small quantity of oil at a time to a high temperature. The apparatus invented by Messrs. Taylor, in 1815, consisted of a furnace, with a contorted iron tube, containing fragments of brick or coke, into which, when red-hot, the oil was allowed to drop. Decomposition of the oil immediately took place, gases were given off, together with the vapours of substances liquid at common temperatures, and there was a considerable deposit of carbon in the retort tube. By an improvement in this apparatus, the exit tube from the retort is conducted into an air-tight cistern or receiver, in which the more easily condensed products are collected in the liquid state, and returned into the retort. The gas proceeds from a pipe leading from the top of the cistern. In Fig. 1049, *a* is the retort, filled with pieces of coke about the size of a hen's egg; *b* the exit tube leading into the cistern *c*, from which the pipe *d* conducts the gas to the gasometer. The coke is changed every two or three weeks, as the interstices become obstructed by the deposit of carbon.

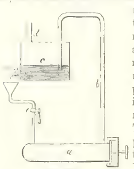

Fig. 1049.

Oil-gas is rich in olefiant gas: it contains neither nitrogen nor sulphuretted hydrogen; but it has more carbonic oxide than coal-gas. Its illuminating power is twice that of the best coal-gas, and three times that of ordinary coal gas. The commonest oil is, however, too expensive in this country to admit of its substitution for coal. A great objection to oil-gas is the gradual liquefaction of some of its valuable hydrocarbons, by exposure to a moderate degree of cold.

Resin is admirably adapted to the manufacture of gas, but, as in the case of oil, its expense will always prevent its introduction where coal can be procured. The apparatus constructed by Professor Daniell for the Resin Gas Company at Bow, consisted of a retort *a*, Fig. 1050, charged with fragments of coke, heated to bright redness by a furnace underneath; a short exit tube *b* was placed below the retort, instead of a long one above it, as in Fig. 1049, the latter having become clogged by the bituminous matter which distilled from the resin; the exit tube *b* was passed into an air-tight cistern or hydraulic main *c*, kept cool by a refrigerator, supplied with water from a cistern above. The volatile oil condensing in *c*, was conducted into another cistern *d*, by the discharge pipe *e*. The uncondensed gases and vapours passed up the pipe *f*, and deposited a further portion of volatile oil in the cistern *g*, from which it was conducted into *d* by a syphon tube. From the cistern *g* the gas passed by the pipe *h* into the gasometer. The large quantity of volatile oil collected in this process, was employed to dissolve the resin in the vessel *i*, which was mixed with oil in the proportion of 8 or 10 lbs. of resin to 1 gallon of oil, the solution of the resin being assisted by the heat of the furnace below. The vessel *i* contained a wire-gauze screen, to prevent any solid resin or impurity from entering the retort; the dissolved resin passed through the stop-cock *k*, funnel, and syphon tube, into the retort. A little acetic acid formed in the oil during the distillation, was got rid of by the addition of lime, before the oil was mixed with the resin. It is stated that 1 cwt of resin will afford from 1,000 to 1,200 cubic feet of gas, of the average specific gravity 850, and that 2 cubic feet of resin-gas will afford as much light as 5 of coal-gas.

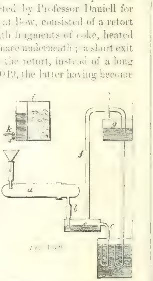

Fig. 1050.

The production of gas from oil, resin, and other refuse matter, has long been neglected in this country, on account of the expense of the crude material. Improved methods have, however, been introduced, and made the subject of a patent by Messrs. Laming and Evans, (dated 23d April, 1850.) According to their method, iron or clay[1] retorts are used; these are composed of two horizontal chambers, one above the other, and communicating at the back only. The ends of the chamber are closed by three man-hole doors, two of which are secured over the front ends of the chambers, and the third, which is a large door, serves to close the hind ends of both chambers, the three doors all projecting beyond the brickwork setting of the retort. Near the front end of the upper chamber is an inverted funnel, of large diameter, closed by a lever, the edge of which is turned down, and dips into an hydraulic joint, or into a joint filled with metal fusible at the temperature to which it is exposed. The cover is fitted with a double syphon, furnished with a stop-cock. The eduction-pipe leading to the hydraulic main is connected with the front end of the lower chamber of the retort. When this apparatus has been raised to the usual temperature, the upper chamber is charged with coke, heaped up just beneath the funnel, and some pieces allowed to fall over against the large man-hole door at the back; the lower chamber is charged with coal or coke. A stream of oil, tar, melted pitch, resin, fat, or other analogous matter, in conjunction with water or not, is then allowed to fall from the double syphon, through the large funnel, upon the red-hot coke; it passes thence, partly as gas, and partly as liquid, through the upper chamber to the back of the lower one, along which it next proceeds, chiefly in the state of gas, and escapes, mixed with the gaseous products of the lower chamber, through the eduction-pipe into the hydraulic main. When the lower chamber is filled with coal, it is allowed to give off its gas, before the liquid is permitted to flow: the process is then continued without intermission, until the passages of the gas apparatus require to be opened and cleaned out.

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[1] One part of this patent is for the formation of clay retorts, by which it is proposed to mix with the fire clay about 0·25 per cent. of its weight of asbestos, or fibrous silicate of magnesia. This is said to give greater tenacity to the retorts, making them less liable to crack when exposed to various ranges of temperature.

Water-Gas. The capital discovery of the composition of water, and the ease with which its two volumes of hydrogen can be separated from its one volume of oxygen, have caused scientific men to look forward—somewhat indefinitely, it is true—to the time when water may come to be used as a source both of light and of heat. The "manufacture of water-gas" was a few years ago keenly discussed,[1] and it formed the subject of a number of patents, such as Donovan's, dated 1830; Lowe's, 1832; Manby's, 1839; Val Marino's, 1839; Radley's, 1845; Lowe's, 1846; White's, 1847. Of all these, probably, the most original and suggestive is Val Marino's; but our limits will not allow us to describe his processes and the causes of failure. The principle of the manufacture of water-gas is to pass steam over red-hot coke, thereby resolving it into two inflammable gases, viz., hydrogen and carbonic oxide, and then to supply them with the requisite amount of carbon for luminosity, by passing them through a retort in which resin or some other carbonaceous substance is undergoing decomposition by heat. In the process patented by Messrs. Barlow and Gore advantage seems to have been taken of the failures and the successes of their predecessors. Their processes are based, *first*, upon an improved method of rendering luminous the gas resulting from the perfect decomposition of water or steam; and *secondly*, upon the *conservative influence* which hydrogen exercises in protecting the matter upon which the illuminating power of gas depends from decomposition by heat. The failure of previous patentees in the attainment of the first point is said to have arisen from the imperfect decomposition of the water or steam, and the production of a large quantity of vapour, which exerted a destructive influence on the carbonaceous matter undergoing decomposition for the purpose of rendering the water-gases luminous. Moreover, a considerable quantity of carbonic acid was produced, and this had to be got rid of by purifying, before the gas could be burnt. The present patentees propose to obviate these difficulties by first *condensing* the water-gases, so as to deprive them of excess of vapour, and then to pass them through a heated retort containing carbonaceous matter, by which the whole of the carbonic acid gas will be converted into twice its bulk of carbonic oxide gas, and the pure hydrogen and carbonic oxide gases, in equal volumes, free from carbonic acid, are afterwards admitted in regulated quantities into retorts where carbonaceous matter is undergoing distillation or decomposition, and by which they are rendered highly luminous. The conservative influence of hydrogen may be illustrated by the following experiment:—If olefiant gas be passed through a red hot tube, the carbon will be deposited, and the gas be converted into light carburetted hydrogen; but if hydrogen be added to the olefiant gas, the same process may be repeated without causing any deposit of carbon, and with only a diminution of illuminating power in the mixed gases due to the increased volume of the hydrogen. The practical effect of this property when applied to gas-making is, to reduce the quantity of condensible products, such as tar, &c., and to prevent the deposit of carbon on the interior surfaces of the gas-retorts. According to the patentees, upwards of 50 per cent. may be added to the volume of gas yielded by all descriptions of materials ordinarily used for that purpose, without any diminution of the illuminating power; so that 15,000 cubic feet is said to be likely to be the future produce from one ton of Newcastle coal, and 75,000 cubic feet of London gas from the same quantity of Boghead cannel, the ashes of which may be used in the manufacture of alum, the residue after the extraction of the alumina being also valuable in the manufacture of pottery, porcelain, and glass, and also useful as a polishing-powder and decolorant.

GAUGING. See GAGING.

GAUZE. A light, transparent silk texture, supposed to have been invented at *Gaza*, in Palestine; whence the name.

GEARING, or GEERING. A term applied to those mechanical contrivances which are interposed between the prime mover and the working parts of machinery for the purpose of transmitting motion. The term is sometimes restricted to the series of toothed wheels by which motion is conducted from one revolving axis to another, without reference to the shafts and bearings by which they are supported. Two toothed wheels are said to be *in gear* when the teeth are engaged together; and *out of gear* when disengaged or separate. See COUPLINGS—WHEELS.

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[1] See the *Journal of Gas-lighting* for the end of 1851 and the beginning of 1852, and even later.

GELATINE is a substance the production of which is limited to the animal creation. When the skin and membranous tissues of animals are boiled in water, the liquor, on cooling, forms a jelly. The bones, tendons, and ligaments, under a higher temperature, also yield a jelly, similar in appearance and in properties to the former, but less agreeable to the taste. [See BONE.]

The ordinary sources of gelatine are clippings of hides, hoofs, horns, feet of calves, cows, sheep, pigs, and various membranes. These are carefully cleaned, then subjected to long boiling, and the liquor strained, skimmed, and allowed to gelatinize: the resulting jelly is stiff and tremulous, and is called *size*. Sometimes the sources from which size is obtained are not so pure as the above, the refuse from the skins of horses, cats, dogs, the cuttings from parchment, vellum, and white leather, and sometimes the membranous parts of fish, being admitted into its composition. Size has an intolerably putrid odour, but it may be purified by the careful application of sulphurous acid. This is sometimes done, the size dried in thin layers, and so used as a substitute for isinglass. Without purification, size is cut into slices, dried, and sold as *glue*.

Isinglass is the purest form of commercial gelatine. The best is prepared from the air-bladders and sounds of three or four species of sturgeon, inhabiting the Black and Caspian Seas, and their tributary streams. These tissues are cleansed, dried, and scraped, forming *leaf isinglass;* or they are twisted into various forms, and called *long* and *short staple;* or folded into packages, called *book-isinglass*. The manufacture is chiefly carried on in Russia, whence we receive the best article. The account given by Martius of the preparation of Russian isinglass is as follows: The swimming bladders of the fish are first placed in hot water, carefully deprived of adhering blood, cut open longitudinally, and exposed to the air, with the inner delicate silvery membrane upwards. When dried, this fine membrane is removed by beating and rubbing, and the swimming bladder is then made into different forms. An inferior variety, called *ribbon isinglass*, is received from America. Isinglass is cut by machinery into the delicate filaments in which we usually see it sold. It is a colourless, inodorous substance, perfectly soluble in hot water. It is largely consumed as an article of food. The purest and whitest isinglass is required for domestic use, entirely free from unpleasant odour, and dissolving readily and completely in water. It forms a very transparent jelly, and is indispensable in the preparation of blanc-mange, ices, creams, and other delicacies for dessert. Inferior isinglass answers the purpose of fining beer, &c. A solid gelatine in thin plates and strings, has lately been introduced to answer the purpose of isinglass. The best is transparent, and is brought from France; it is prepared from the gelatine of bones by digestion in dilute hydrochloric acid and long boiling in water. It is much cheaper than isinglass, but it is inferior in nutritive power and digestibility, properties which are diminished by long decoction. The same may be said of another substance called *patent opaque gelatine,* which is prepared from the cuttings of skins, and is therefore a kind of glue. Sources from which these substitutes are procured are not the most agreeable; nor is it likely that in the more delicate preparations of the table they will ever take the place of isinglass. Jellies were formerly supposed to be exceedingly nutritive, and especially suitable for invalids; at present medical testimony leads to the opinion that they are less so, and even less digestible than the flesh or muscular part of animals. Isinglass is made in India, and has long been exported thence to China. In most cases it has a very unpleasant fishy odour, which renders it totally unfit for domestic use. Cod sounds, in the dried state, are brought from Scotland, and used as a substitute for foreign isinglass.

Diamond cement, or white fish-glue, is made of isinglass dissolved in dilute spirits of wine or common gin. The two are mixed in a bottle loosely corked, and gently simmered in a vessel containing boiling water; in about an hour the isinglass will be dissolved, and ready for use. When cold, it should be an opaque, milk-white, hard jelly: it is remelted by immersion in warm water, but the cork should be at the same time loosened. After a time a little spirit should be added to replace that lost by evaporation.

But the best *isinglass glue* is made by first soaking good isinglass in cold water; when swelled, it is to be put into the spirit, and the bottle containing it set in a pipkin of cold water, which may be brought to the boiling point, when the isinglass will melt into a uniform jelly, free from lumps or strings. The addition of a little essential oil diminishes its tendency to become mouldy.

GLUE is a highly useful and important substance, and its manufacture is carried on upon a large scale, as follows: the parings of hides and pelts from the tanners' and furriers', with the refuse materials already enumerated for gelatine, are the substances from which it is extracted in Britain. These are first placed in a lime-pit, and when sufficiently steeped, they are carried in baskets to a stream of water and rinsed, after which they are placed on hurdles to dry. Whatever lime remains adhering to them is converted into chalk by the action of the air; and though lime would be injurious to the after processes, yet the presence of a small portion of chalk is immaterial.

The pieces having been thus cleansed, the next process is the extraction of the gelatine from them by boiling. For this purpose they are placed in a wide-mouthed bag or net, made of rope, and spread open within a large iron caldron. A light framing of iron within the caldron prevents the bag from sticking to its sides. Water is then added, and gradually brought to the boiling point; as the animal substances sink, fresh quantities are added, the whole being occasionally stirred up and pressed down with poles. The state of the substances is tested by occasionally taking out a portion, and setting it aside to cool: if a clear mass of jelly be produced, the boiling has been sufficient. The mouth of the bag is then closed by means of cords, and the bag is slowly hoisted by machinery until it rests against, or partly coils round a beam immediately over the caldron, which helps to press out the liquid. See Fig. 1051. In this state it is left to drain. Meanwhile the contents of the caldron, if not strong enough for glue, can be further evaporated by continuing to apply heat. The contents of the bag are boiled a second and a third time for making size; and when the solutions are too weak for either glue or size, they are economically used instead of water. The last remaining refuse is sold for manure. Thus, every portion of animal substance is turned to profitable use.

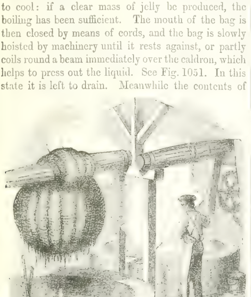

Fig. 1051. GLUE CALDRON.

The glue in the caldron, when thick enough, is drawn off into a vessel called a *setting back*, and maintained at a temperature which will keep it liquid. This gives time for the deposition of solid impurities, and for further clarification by the addition of such fining substances as the manufacturer may prefer. The glue is then run off into wooden coolers about six feet long, one foot broad, and two feet deep. Here it becomes a firm jelly, which is cut out by a spade into square cakes, each cake being deposited in a sort of wooden box, open in several slits or divisions to the back. The glue is cut into slices by passing a brass wire, attached to a kind of bow, along the slits. These slices are placed upon nets, (the marks of which are seen on the dry glue,) and stretched in wooden frames, and are thus removed to the glue-maker's field, where they are placed in piles, with proper intervals for the admission of air, each pile being roofed in, as a protection from the weather. The glue is turned two or three times a-day, and for this purpose the roof is lifted off the pile, and the uppermost frame placed on the ground. The cakes are turned one by one, and then the second frame is lifted off and placed on the first. The operation is thus repeated until a new pile is formed near the spot where the old one stood, when the roof is replaced.

During the drying the glue is more likely to receive injury than at any other period. In very warm weather the cakes are liable to become so soft as to lose all shape and unite with the frames, or they may even melt entirely, and flow away. A thunder-storm sometimes prevents a whole field of glue from hardening; while a thick fog may make it all mouldy. A brisk drying wind may harden it so suddenly as to render it unsightly and unfit for the market. A hard frost, by freezing the water in the glue, may cause it to crack in all directions, rendering re-melting necessary. Thus the manufacture has many vicissitudes to suffer, and can only be profitably and conveniently carried on in temperate and equable weather. The drying, however, is not entirely finished in the open air. When the glue is about three-parts dry, it is removed into lofts, where, in the course of some weeks or months, the hardening is completed. But as the surfaces of the cakes become mouldy and soiled, it is at length necessary to scour them with a scrubbing-brush and hot water, and set them up to drain. They are then finally dried off in a stove-room at an elevated temperature, which, when they are once solid, only serves to harden and improve them.

After stove-drying the glue is fit for the market, where it is judged of by its strong dark colour, and freedom from cloudy or black spots when held to the light. The better sorts of glue are transparent, especially the thin cakes of the *Salisbury glue*, which are of a clear amber colour. The best glue swells without melting when immersed in cold water, and renews its former size on drying. The method of softening it for use is to break it into small pieces, soak 24 hours in cold water, and then melt slowly over a fire with frequent stirring. When prepared in this way it cools down into a stiff jelly, which requires only a little warming to fit it for use. Glue must not be used in a freezing temperature.

A strong compound glue is made by infusing common glue in small pieces with isinglass in spirits of wine, just sufficient to cover the mixture. Heat is then cautiously applied, and when melted, powdered chalk is added, making the whole of an opaque white. A strong glue, which will resist water, is also obtained by adding half a pound of common isinglass to two quarts of skimmed milk, and evaporating the mixture to a proper consistence. If gelatine which has been swelled in cold water be immersed in linseed-oil and heated, it dissolves and forms a glue of remarkable tenacity, which, when once dry, perfectly resists damp. Ordinary glue may be thus dissolved, and a small quantity of red-lead, in powder, added.

It appears from the observations of M. Schattenmann, a glue-maker, (Annales de Chimie, 1845,) that fresh glue dries much more readily than glue that has been once or twice melted; and that dry glue steeped in cold water absorbs different quantities of water according to the quality of the glue; and the proportion of water so absorbed may be used as a test of the quality of the glue.

It appears that fresh glue contains water of composition, or water more intimately united with the glue than water mixed with it in the process of melting, which admits of being readily disengaged by evaporation. The combined water of dry glue disappears in the course of successive meltings and solidifications to which glue is subjected. Glue in thin plates is usually of better quality than thick ones, even when made with the same kind of gelatine, because the thin plates admit of a more complete drying than the thick.

In applying M. Schattenmann's test, dry glue is immersed for 24 hours in water at the temperature of about 60° Fahr. A jelly will thus be formed, the qualities of which will fairly represent those of the glue. For example: the finest ordinary glue, or that made from white bones, absorbs 12 times its weight of water in 24 hours, so that a plate weighing 3 grammes produces 39 of fine elastic jelly. Glue from dark bones absorbs 9 times its weight of water, and produces not quite so fine a jelly. The ordinary glue of Alsace or of Germany, made from animal refuse, absorbs 5 times its weight of water, producing a soft brown jelly, without elasticity and consistence, and falling to pieces when handled. The common glue of Bologne absorbs 3½ times its weight of water.

Well dried glue is much less hygrometric than badly made glues, or those made of inferior materials. The latter are liable to putrefaction. The water of composition seems to be injurious to the strength of glue, which increases in proportion to its dryness.

Marine glue has no gelatine in its composition. It is noticed under Wood, p. 1025.

Glue or gelatine has lately been applied, with great success, to the formation of moulds for casting. The difficulties attending the use of sand, clay, plaster of Paris, wax, &c. in forming moulds for casting, are very great where the objects to be repeated are complicated in form. About the beginning of the present century the Germans introduced the use of glue for making moulds, which was not employed in this country until about the year 1826, when Mr. Douglas Fox used it to take casts from anatomical preparations, calcareous concretions, vegetable substances, &c.; and in order to give greater elasticity to the moulds so obtained, and to keep them in a fit state for use during a long period, he mixed treacle with the glue: this, however, was found to discolour the surface of all white bodies, and its application being limited by this objection, the plan was abandoned. About the year 1844 attention was again called to this subject by the production in France of a series of casts in imitation of ivory; and about 1846 the Society of Arts, London, offered a prize which was awarded to Mr. Franchi for his specimens of casting in plaster composition in imitation of ivory. At the time the award was made, the nature of the material used by him was not known; but it has since proved to be pure gelatine, and owing to the skilful use of his material some exquisite electro-type casts deposited in the Geological Museum were obtained from objects greatly under-cut. Mr. Franchi has since found that he can obtain from a gelatine mould a cast in gelatine in relief without losing any of the sharpness of the original. This has enabled him to apply objects modelled on flat surfaces to cylindrical bodies, thus saving the labour and expense of modelling. One great advantage of gelatine moulds is, that casts without seams can be taken from them.[1]

Gelatine in a great variety of forms and colours was displayed in the two Great International Exhibitions, as will be noticed in the Appendix.

GEMS. The various gems and precious stones used in the arts are noticed separately under their respective names. The conversion of gems to purposes of ornament will be described under Lapidary-work: for the art of engraving on gems we must refer to Seal-engraving.

GERMAN SILVER. See Nickel.

GILDING. Gilding on wood is a distinct trade from gilding on metal; the processes and tools employed are likewise different. Gilding on wood is of two kinds, distinguished as *burnish-gilding* and *oil-gilding*. The processes connected with burnish-gilding are as follows. If a plain picture-frame has to be gilded, the gilder receives it from the hands of the joiner, not in the shape of a picture-frame, but in one long levelled moulding extending 12 feet in a straight line. This he has to prime and prepare for gilding by a number of processes, which cannot be abridged without detriment to the final effect. He first gives it a priming of hot size and whiting, called *thin-white*. The size and also the whiting employed for this purpose must be of the best kind, the whiting being finely powdered and stirred in, in small quantity, while the size is being melted in an earthen pipkin. This first coating of thin-white being dry, all holes and irregularities in the moulding are afterwards filled up with a mixture of whiting and size made of the consistence of putty, but differing from ordinary putty in containing no oil. After this, the moulding receives four or five layers similar to the first, but of greater consistence, and therefore called *thick-white*. These are laid on with a brush, and time is allowed between each layer for the work to dry. That the fine work of the moulding may not be filled up, opening tools, such as crooks, chisels, gouges, &c. are employed while the thick-white is still wet. The forms of the various mouldings are perhaps better retained by using the *double-opening-white*, that is, two thick whites laid on, the one almost immediately after the other, and worked into the shape of the mouldings, by hard stones of the required form, used in conjunction with the opening tools.

The body of the whiting, which is now from one-sixteenth to one-twelfth of an inch in thickness, is necessarily uneven at the edges, so as to require trimming. This is the next operation, after which the whole is smoothed by pieces of pumice-stone, adapted to the forms of the various parts, which are slightly wetted, that the rubbing may have the more perfect smoothing effect. Care must be taken, however, not to rub off too much of the whitening, as the beauty of the frame mainly depends on the good body or foundation for the gilding. Glass-paper is also used to give the final polish. The moulding is now ready for a particular sort of size which adapts it for gilding. This size is put on in from four to eight coats, with dryings between. It is a remarkable substance, consisting of pipe-clay, red-chalk, black-lead, suet, and bullock's blood, and is sold to the gilder in a tenacious mass, rather softer than butter. A portion of this gold-size is melted with thin clear size of the ordinary kind, and laid on while barely warm, with a brush, and with great nicety of hand. The best test of good work is to produce the smoothest surface with the least loss of gold-size.

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[1] Journal of Design, July 1851

The final processes require several gilding-tools. These are, first, the *cushion*, a flat board, eight inches by six, covered with layers of woollen cloth, or flannel, over which is strained a piece of leather, nailed down tightly to the edges of the wood. Along one of the short sides of the cushion, and reaching round half of each of the two long sides, is a rim or border of parchment, three inches high, as a safeguard to the gold-leaf which is to be laid on the cushion. The other sides are left open, to facilitate the cutting of the said leaf into strips. The *knife*, for cutting gold-leaf, is straight, smooth-edged, but not very sharp, and ends in a well-defined point. The tool for laying on the gold is called a *tip*, and consists of two pieces of card glued together, with the ends of a row of camel-hairs confined between them, the remaining portion of the length of the hairs protruding from the cards to a distance varying from one inch to two inches and a half. Sometimes these cards are circular, and have a little wooden handle springing perpendicularly from the centre.

Gold-leaf is supplied to the gilder in books, twenty-five leaves to each book; and this, with the gilding-tools, being ready, the work proceeds as follows. The gilder takes the cushion, and supports it on his left hand by means of a leather loop underneath; the open end of the cushion being towards the right. He then places the tip, the knife, and a camel's-hair pencil, between the fingers of the left hand, that each may be immediately at hand when required. Thus armed, he may be compared to the oil painter, with his palette and brushes, all ready for action.

Taking the book of gold-leaf, he has now to convey the required number of leaves for the work he has in hand from the book to the cushion. This requires some care, on account of the fragile nature of the material. It is effected without touching the leaf, simply by the breath. Each leaf is blown gently from its place in the book, on to the cushion, though a learner will occasionally blow wide of the mark. The breath also afterwards assists in raising and spreading one out of the confused heap of leaves on the cushion, and adjusting it in front, where it is to be cut out in strips according to the width of the moulding. In a moulding which has deep depressions, several lesser widths of gold must be used, as a strip of the whole width of the moulding would be torn in fitting it to the hollows, and would exhibit irregular fractures, called by gilders *spider-legs*. According to the width required, therefore, he cuts the sheet into four, three, or two strips. It is seldom that a larger piece than half a leaf is used at once.

A few inches of the moulding about to be gilded are first wetted with water, laid on with a camel's-hair pencil; the moisture not to extend beyond the first leaf. The gilder then applies the tip to a strip of gold, which slightly adheres to the hairs; from whence he transfers it steadily to the moulding. When the hairs of the tip fail to take up the gold, they are rubbed between the cheek and the palm of the hand, when the friction brings them into proper action. When the gold is laid on, it is blown forcibly to expel as much of the moisture as possible from underneath it, a dry camel's-hair pencil being used to press down any parts which do not adhere. Another portion is then wetted, and another piece laid on, overlapping the other by about the eighth of an inch. Thus piece by piece, and one width after another, the whole moulding is completed and set aside to dry. There is a particular state of dryness, known only by experience, when the work is fit for burnishing. The burnishers are either of flint or agate, and they can be rubbed briskly over the gold, not only without injuring it, but to the great increase of its brilliancy. This is owing to the foundation of gold-size and whitening, which forms a yielding substance under the hand; but the burnishers require peculiar handling to be used with the proper effect. They are of various shapes and sizes. When the burnishing is done, attention must be paid to certain parts of the gilding which are to be in dead gold, called *matt*, and which have consequently been left unburnished. Over these parts a very thin clear size is passed, and when dry the gold is wiped carefully with soft cotton wool, and any little defects remedied by adding small pieces of gold-leaf. When these are also dry, the whole is completed by wetting with clear finishing-size on the matt parts with a pencil. The moulding is now complete, and passes into the hands of the frame-maker, who cuts it up and joins it in the required manner for the picture; after which the gilder has again to take it in hand to stop up and conceal any nail holes, and to paint the outside yellow, for it seldom happens that the outside is gilt.

For a richly-ornamented frame, where oil gilding is required, the processes are rather different. The moulding is whitened as before, but it is then made up to the required shape, and is decorated with composition ornaments of a more or less elaborate character. The gilder receiving the frame thus, first washes it to free it from oil. He then gives it two or three general coatings of very thin white, in which a little clay, of a peculiar mellow texture, has been mixed. Further coatings must be given to the parts intended for burnishing. The frame is now ready for *clear-cole*, a moderately strong size, of which two or three coats are laid on. After this comes what is called oil gold-size, which is a mixture of boiled linseed-oil and ochre, laid on as smoothly as possible with a brush. This oil gold-size being laid on over night, the frame is generally in the proper state on the following morning for gilding. This is effected in the same manner as before, except that no water is used, the partially dried oil answering the same purpose, and the gold is cut into rather differently shaped pieces, according to the inequalities of the ornamented frame. When the ornaments are very deep, the gilding has to be repeated, and the gold pressed in with cotton. The work has at first a ragged and unequal appearance, but is brought into order and regularity by means of a brush, with which every part is carefully gone over, superfluous gold being removed from some parts, and worked into others. To do this well, without scratching or disturbing any portion of the surface, requires considerable skill. The process is called *skewing*, and the particles of gold collected from it, are sold under the name of *skewings*. The clear-cole and oil gold-size are kept carefully away from any parts designed to be burnished, which must be treated as before described. After the frame is skewed and dusted, it is sized with clear size, and yellowed on the outside. The smoothing of elaborate frames is not effected wholly by pieces of stone, but by seal-skin, Dutch rush, and pieces of linen cloth.

In regilding old frames it is usual to wash off the old gold and a portion of the gold-size beneath, to stop up holes with putty, and then to lay on new gold-size, and re-gild. If the frame has been gilt in oil-gold, that cannot be washed off, but must be scoured clean preparatory to the after processes.

For gilding on metal, or water-gilding, see BUTTON. This unhealthy occupation is now nearly superseded by Electro-gilding. See ELECTRO-METALLURGY. The composition of gilding-metal for common jewellery is described under BRASS. The gilding of the leather and of the edges of the leaves of books, is described under BINDING. For the gilding of PORCELAIN, see POTTERY and PORCELAIN, Sec. IX.

GIN, from *Genera*, or *Genièvre*, the juniper. See DISTILLATION.

GIN, a contraction of *en-gine*. See COTTON.

GINGER (*Amomum zinziber*), a plant, whose roots are valued for their pungent qualities. It appears to be a native of India and China, but succeeds remarkably well in the West Indies, where it was carried at a very early period, and whence the finest ginger is now obtained. It is received in two states—preserved, and dried. In the former, the roots taken up when they are young and full of sap, are scalded till they are tender, then peeled and covered with a thin syrup. From this they are afterwards removed, placed in jars, and a richer syrup poured over them. In this state they reach us, forming one of the most delicious and wholesome of preserves. Dried ginger of the best kind consists of the best roots scraped, washed, and dried in the sun until they are quite white. Inferior roots, scalded in boiling water before drying, are of a dark colour, and obtain an inferior price as black ginger. The domestic uses of ginger are well known. It is considered a good stomachic, and an improver of digestion in languid habits. The consumption of ginger in this country is stated at about 10,000 cwt. per annum.

GIRDER. See CARPENTRY—FLOORS AND PARTITIONS—ROOF. Iron girders are also noticed in BRIDGE, *Section VI.*, and in FIRES—FIRE-PROOFING, page 669.

GLASS. The discovery of glass is one of the great triumphs of the useful arts; for what can be more admirable than that the application of heat to certain widely different materials, all more or less opaque, should produce a homogeneous transparent substance, capable of being moulded under the continued application of heat into every variety of form, and permanently retaining that form when the heat is withdrawn? This discovery was made long before science can be said to have existed, yet it has been of as much importance in assisting the advancement of science as in favouring the progress of civilization.

The use of glass in our windows, instead of the louvre-boards of our ancestors, has introduced comfort into the meanest dwelling which previously did not belong to the richest palace. By means of this contrivance the light is filtered from the wind, the rain, and the cold; we can enjoy the one without being inconvenienced by the others; and we can, in conjunction with our methods of warming, create an in-door climate adapted to our feelings and desires. The use of glass in many of our domestic articles of furniture and vessels contributes to cleanliness and health, for the slightest soil on our glasses and decanters is revealed by this most transparent material, and the purity of the water and other liquids contained in them is physically tested by the same means. Even the mirror, which adorns our rooms, reminds us of the necessary attention to personal appearance, which self-respect as well as respect for society demands. By means of glass the eye of advancing age regains something of its youthful vigour. By means of glass the astronomer makes us acquainted with distant spheres, and the naturalist with the inhabitants of a drop of water. By means of glass the natural philosopher has discovered the physical marvels of the atmosphere; and the chemist, its equally wonderful chemical properties. Indeed, science is greatly indebted for its progress to the transparent chambers of glass of every variety of shape and form so easily and so cheaply procured, within whose transparent walls processes can be isolated and watched without danger to the operator. The whole of pneumatic chemistry depends on glass; as does also the existence of many of the most valuable acids, which could never have been discovered, or if discovered, preserved for any length of time, but for glass retorts and glass bottles.

SECTION I.—HISTORICAL NOTICE.

The honour of this great discovery has been assigned to the Phœnicians. It is stated by Pliny that some mariners who had a cargo of *nitrum* (probably soda) on board, having landed on the banks of the river Belus, a small stream at the base of Mount Carmel in Palestine, and finding no stones to rest their pots on, placed under them some masses of nitrum, which, being fused by the heat with the sand of the river, produced a liquid transparent stream of glass. It is difficult to imagine how such a result could have been produced under the very moderate heat of an open fire. However this may be, the Sidonians of the neighbourhood are said to have improved upon the discovery, and to have practised the new art with considerable success. It would be much more philosophical to suppose that the discovery of glass originated in the practice of some of the more ancient arts, such as the firing of bricks, or earthen vessels, and the reduction of metals from their ores, in which processes vitrifiable materials exposed to an intense heat, lead to the production of an impure glass, or slag.

Materials for a connected history of glass do not exist; but it appears from the researches of learned men that the art of glass-working was practised in Egypt before the exodus of the children of Israel from that land, 3,500 years ago. Glass-blowers at work are represented on some of the monuments, which are proved by the accompanying hieroglyphics to be as old as that event. *Glazed* pottery was known at the same period; and there has been found at Thebes a glass bead, about ¾ inch diameter, of the same specific gravity as our crown glass, on which is inscribed the name of a monarch who lived 1500 B.C. The Egyptians also counterfeited precious stones in glass: they used it for drinking-vessels, for mosaic work, the figures of deities, and even for coffins.

The Jews appear to have carried with them from Egypt a knowledge of the art; and subsequently the Greeks and Romans, who successively conquered Egypt, acquired the art from the same remarkable people, or, at least, discovered among them a source of supply for articles in glass. The glass-houses of Alexandria were celebrated among the ancients for the skill and ingenuity of their workmen. The cinerary vases of greenish glass in the British Museum, which were found in Roman barrows, are supposed to be of Egyptian or Roman manufacture. Glass vessels have been found among the ruins of Herculaneum: and there is evidence that glass was used for admitting light to dwellings in Pompeii. From these, and similar notices of the early history of glass, it is evident that it was during many ages a costly luxury. We must, however, suspect some exaggeration in such statements, as, that Nero paid 6,000 sestertia, or nearly 50,000*l.* sterling, for two cups of clear glass, if such a price is to be taken as a representative of the value of glass at the period in question. The statements of the gossiping Pliny must always be received with caution: but even he does not confirm the above account, but only remarks that in his time the superior kinds of glass were in such extensive use as almost to have superseded cups of the precious metals.

Glass-making in Britain appears to be of ancient date. The Druids are said to have manufactured beads and annulets. Glass vessels were made by the Anglo-Saxons. The *snake-stones* found in Wales are glass beads, which were used by the Druids as a charm: they are usually of a green colour, but some are blue, and others curiously variegated with waves of blue, red, and white. The *aggry beads* of Ashantee, which are occasionally dug out of the earth, are of great beauty; their variegated strata are "so firmly united, and so imperceptibly blended, that the perfection seems superior to art: some resemble mosaic work; the surfaces of others are covered with flowers and regular patterns, so very minute, and the shades so delicately softened one into the other, and into the ground of the bead, that nothing but the finest touch of the pencil could equal them. The agatized parts disclose flowers and patterns deep in the body of the bead; and thin shafts of opaque colours, running from the centre to the surface." Mr. Bowdich, who thus describes them, thinks it not improbable, "that in the golden age of Egypt she had communication with the Gold Coast; indeed, it has been thought, and perhaps not without some reason, that the Gold Coast is the Ophir of Solomon."

The Chinese, who have been celebrated from ancient times for the manufacture of porcelain, do not seem to have attained any proficiency in the kindred art of glass-making. They are skilful in imitating precious stones in vitreous substances, but even at the present time they do not appear to be acquainted with an economical method of making glass from the raw materials. They are accustomed to import glass from Europe, which they break up, re-melt, and convert into such articles as they require. There is a royal glass-manufactory in Pekin, which is carried on as much for amusement as for profit.

To Venice belongs the honour of first making glass so cheap as to allow of its more general introduction. Her glass-houses on the island of Murano were, during two or three centuries, the only manufactories of drinking-glasses and mirrors; and on their introduction into other countries, she continued to excel the rest of Europe, especially in ornamental kinds of glass. Venice was celebrated for that kind of ornamental glass, the manufacture of which has recently been revived in the form of letter-weights, and named by the French *mille-fiori* glass, in which a number of coloured flowers and glass ornaments are imbedded in a lump of transparent white glass. The Bohemians successfully imitated the Venetians in the manufacture of ornamented glass. The French government was so desirous of introducing the manufacture into France, that in the time of Louis IX. a law was passed allowing none but gentlemen or the sons of nobility to establish a glass-house, or even to work therein. Traces of the gentility of the art which thus originated, were to be found in France not many years ago, and even in England the workmen were accustomed to style themselves "gentlemen glass-blowers." The French artists, who had been instructed by the Venetians, were incorporated by royal charter with many important privileges, and were established by the government at Tourlaville, near Cherbourg,[1] in the

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(1) This spot was selected because [illegible] tures it [illegible] than any other in France, the [illegible] of

year 1665. The art continued for some years to be almost literally that of *blowing;* but in 1688 the art of *casting* was invented, or rather revived, by Thevart, who, having obtained a patent for his invention for 30 years, established works at Paris for the manufacture of *plate* glass: the works were soon removed to St. Gobain, in the department of the Aisne, which, for more than a century, was the only place on the continent where cast-plates for mirrors could be procured. The invention is said to have been suggested by the accidental breakage of a pot containing melted glass, some of which flowed under a large flag-stone: on removing this, the glass was found in the form of a plate, such as could not be procured by blowing.[1]

The Italians were the first to apply glass to the making of cameos and intaglios.

The first English glass-houses were those of Crutched Friars, London, established in 1557, for the manufacture of window-glass; and Savoy House, in the Strand, established shortly afterwards for the manufacture of flint-glass; but it was not until 1670, in the reign of William III., that the art of making the fine Venetian drinking-glasses, so much in request, was perfected. Three years after this a plate-glass establishment was begun at Lambeth, but another century elapsed before any work of the kind on a large scale was in existence. In 1771 the British Plate-glass Company received its charter, and erected extensive works at Ravenhead, near St. Helen's, in Lancashire, which are still in active operation. The progress of the glass manufacture in England was rapid, in spite of the incubus of the Excise laws under which it laboured until the year 1845, and our white crystal glass, and even our plate-glass, obtained a superiority over that of any other country, the plate-glass of St. Gobain excepted, for this is probably the best in the world. Since the manufacture has been emancipated, the improvements have been important and rapid: glass is every day receiving new forms and new applications; and even the celebrated ornamental glass of Bohemia is now being rivalled by that of England. A clear perception of beauty of form and harmony of colour is beginning to be felt by the public: this will lead to a demand for articles designed under the influence of good taste: competent artists will arise to gratify it, and manufacturers will be eager to employ them. We are sure that progress in art-manufactures depends as much upon the education of the public as on that of the manufacturer. The influence which they exert upon each other is doubtless reciprocal, as all influence is: if the public taste be bad, the choicest products of art-manufacture will not do much to improve it; and the best artist will have to complain of neglect, because he is either before his time or out of his sphere. On the other hand, if the taste of the manufacturer be not at least *equal* to that of his best customers, they will gratify it in foreign markets, instead of employing him.

SECTION II.—THE MATERIALS AND CHEMISTRY OF GLASS.

The term *glass*, in its widest sense, is applied to those mineral substances which liquefy and become transparent or translucent on the application of heat, remain so on cooling, and exhibit in their fracture what is called a *vitreous* lustre. The term is, however, more commonly confined to a few mineral compounds of saline constitution, by which is meant those substances consisting of an acid in combination with a base or metallic oxide. In the case of glass the acid is *silica* or *silicic acid*, and the base a mixture of an alkaline with an earthy base, such as lime, or with the oxide of one of the heavy metals, such as lead.

Silica, silicic acid, or oxide of silicon, consists of 1 equivalent of silicon $= 15$, and 2 of oxygen $= 16$, making 31, the equivalent of silicic acid. Silica exists in great abundance in nature, forming a principal constituent in rocks and stones, and existing in a free state in flint, agate, calcedony, rock crystal, and quartz, the last two being its purest form. Its insolubility in water and most liquids renders its acid character, *viz.* its disposition to unite with alkaline bases, not very obvious. At a red-heat, however, silica acts the part of a powerful acid, and is capable of expelling carbonic acid, muriatic acid, &c., and combining with bases to form solid compounds, or salts, termed *silicates.* Even the continued digestion of silica in an aqueous solution of an alkali, leads to the formation of a silicate; 1 part of anhydrous potash, assisted by the heat of a wind furnace, will bring into fusion 10 parts of silicic acid: by increasing the proportion of potash, a white enamel is obtained: 1 part of anhydrous soda will unite with 12 parts of silica.

The silicates thus formed are soluble in water, and can be decomposed by acids; hence, they are useless as glass. The silicates of the earths, such as silicate of lime, possess the same properties of easy fusibility, solubility, and decomposition as the silicates of the alkalies, but in a less degree. In forming silicate of lime, the strongest heat of a wind furnace is required, and the compound is not *vitreous,* like the alkaline silicates, but *stony,* and slightly translucent, like porcelain. Silicate of alumina requires a very strong heat for its artificial production. Silicates of the metallic oxides are formed without much difficulty. Silicic acid and oxide of lead unite in atomic proportions. Protoxide of iron forms several definite compounds with silicic acid, which are black or dark olive grey in colour. These silicates of the heavy metals are easily attacked by substances possessing a tolerably strong amount of affinity for the base.

Thus it will be seen that no one of the above silicates is adapted of itself to form glass. No single

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Murano; and the success of the Venetian glass-houses was partly referred to advantages of position with respect to the prevailing winds, &c. The idea is not altogether futile, for it is still a common remark among glass-blowers, that the annealing furnace works best when the wind blows in the direction from the hottest to the coolest part. They are exposed to loss and difficulty when the wind blows in a reverse direction, and it is found almost impossible to stop out the reverse current.

(1) St Jerome states that in his time, A.D. 422, glass was melted and cast into plates for windows. About a century later Paulus Silentiarius notices the windows of the church of St Sophia, at Constantinople, as being covered with glass.

silicate is transparent, free from colour, fusible at a moderate heat, and insoluble in water. It happens, however, fortunately, that mixtures of different silicates possess all these valuable properties in various degrees. By a judicious mixture, the earthy and metallic silicates lose their opacity and disposition to crystallize, and the alkaline silicates are deprived of their solubility.[1] The temperature at which the combination of two silicates fuses is something intermediate between the high heat required for the earthy silicates and the low temperature at which the metallic silicates fuse, and this intermediate temperature is much more convenient for working.

The silicates which are formed by the hand of art differ in one essential particular from those which exist so abundantly in nature; that is, they are *amorphous*, or non-crystalline in structure. There is, however, one silicate, that of alumina, which has a great tendency to crystallize; but by combining this with some other simple silicate, it becomes amorphous. Most clays are silicates of alumina; felspar is a silicate of alumina and potash; mica is a silicate of alumina and lime.

Potash, or soda, or mixtures of both, are essential ingredients in all the common kinds of glass: the different properties of the various kinds are mainly produced by varying the quality and proportion of the base of the earthy or metallic silicate. Regarding glass as a chemical, and therefore as a definite compound, the various kinds have been distributed in the following manner:—

1. Silicate of potash and oxide of lead. Examples:—*flint*, *crystal*, and *strass*. Flint contains more lead than crystal, and strass more than flint.

2. Silicate of soda and lime; or, silicate of potash, soda, and lime. Examples:—*common window*, *English crown*, and *plate*.

3. Silicate of potash and lime. Examples:—*foreign crown*, *refractory Bohemian glass*.

4. Silicate of soda, lime, alumina, and oxide of iron. Example:—*coarse green wine-bottle glass*.

The silicate of lead imparts brilliancy and fusibility to all silicates infusible by themselves; but an excess of lead gives a yellowish tint. Silicate of lime imparts hardness, as does also silicate of alumina; and the silicate of iron gives the dark colour to common bottle-glass. Potash and soda render glass easy of fusion, especially the former.

In mixing the ingredients for making any particular kind of glass, the law of equivalent proportions is not observed. Indeed, there is no kind of glass in common use that is not considerably older than the date of the discovery of this grand law. This is one of those instances, so common in the useful arts, in which success has been attained by empirical means, with no aid from science. It is true that science steps in, and reads a lecture full of instruction to herself on the art of making glass, but scarcely, if at all, benefiting the glass-maker, who still continues to mix his materials according to old recipes, and to preserve his secrets, as he calls them, with jealous care.

The silicic acid is practically represented by fine sea-sand. Flints, calcined and ground, were formerly used, and hence the name of *flint-glass*. The sand consists of minute grains of quartz, rounded by attrition. It is liable to be contaminated with oxide of iron, the presence of which would impart a sensible green tinge to the glass. This oxide of iron might apparently be washed out by means of muriatic acid; but the makers of flint-glass prefer sand which is free from iron, such as the white sand of Alum Bay in the Isle of Wight, the sand of the port of Lynn in Norfolk, the sands of Reigate, Leighton Buzzard, and St. Helen's in Lancashire. Vessels from Sydney and New Holland are freighted back to England, or are ballasted with a fine sand, much prized by the glass-makers. The sand is always cleaned by washing in water; and it is said that the Isle of Wight sand requires about eight waters to cleanse it from chalk and other impurities. After washing, the sand is heated to redness, to burn off vegetable matters: when cold, it is sifted through lawn sieves, to separate the larger grains, pieces of fuel, &c.

Carbonate of potash, or pearlash, is imported for the glass-maker from British America and Russia: it is contaminated with sulphate and muriate of potash, and other impurities. These are separated by dissolving the potash in water, and when the impurities have subsided the lye of refined carbonate of potash is drawn off by a syphon, and evaporated to dryness. Pure carbonate of potash is, however, now manufactured from the alkaline residue of the nitric acid manufacturers, viz. sulphate of potash. The alkali-makers also supply the glass-makers with refined pearlash.

Lead is used either in the form of litharge or of red lead. Red lead ($Pb_3 O_4$) is preferred to litharge, (PbO,) on account of its finer state of division, its pulverulent form, and also because it is decomposed in the glass-pot into ordinary protoxide of lead, and oxygen; the latter, in escaping, serving to oxidise and remove many impurities, such as carbon, which would impart a brownish colour to the glass. Saltpetre is usually added in small quantity, to increase the dose of oxygen, and to assist in driving off the globules of air entangled in the liquid glass.

A few ounces of black oxide of manganese are usually added to the materials for making flint-glass. The presence of manganese assists in clearing the fused mass of colour arising from carbonaceous matters

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(1) This statement is practically true, but, in strictness, even the best made glass is to a certain extent soluble. If finely-powdered window-glass be placed on turmeric paper and moistened with water, it will exhibit an alkaline reaction. Griffiths extracted 7 per cent. of potash from flint glass powder, by boiling it for weeks together with water, and repeatedly re-grinding and washing it. The action of rain and moisture on window panes is to wash away the alkali, and expose a very thin layer of silica or of silicate of lime, which often exhibits prismatic colours. Specimens of ancient glass, which have been dug out of the earth, often exhibit a pearly lustre, resulting from pure silica, the alkali having been slowly removed by long exposure to damp.

A *soluble glass* is sometimes made for the purpose of brushing over the woodwork of houses, theatres, &c., in order to render it fire-proof. Such a glass may be made with 70 parts carbonate of potash, 54 carbonate of soda, 152 ground flints or quartz sand. The solution will penetrate the pores of wood with ease, and leave a vitreous coating.

and protoxide of iron. When the green silicate of the protoxide of iron comes in contact with one of the higher oxides of manganese, it abstracts some of the oxygen of the latter, and becomes converted into silicate of the peroxide of iron, which is almost colourless compared with the silicate of the protoxide. By thus parting with oxygen, the peroxide of manganese becomes reduced to the protoxide, which combines with silicic acid to form a colourless silicate. The carbonaceous matters are also oxidised by the peroxide of manganese, their carbon being converted into carbonic oxide and carbonic acid gases. This cleansing action of manganese has given to it the familiar title of *glass-makers' soap*. It must, however, be used with care, for, if slightly in excess, a lilac or amethyst colour is given to the glass, in consequence of the formation of a compound of silicic acid with sesquioxide of manganese. The remedy for an accident of this kind is to introduce a pole of wood into the coloured mass, and quickly stir it up, when the sesquioxide becomes reduced to the protoxide, and the lilac colour disappears. This operation resembles that of *poling*, described in the article COPPER.[1]

Such is, or rather ought to be, the action of manganese as an ingredient in glass-making. Some manufacturers, however, use it to disguise the bad colour of the other materials, which yield a green glass, *i.e.* a glass which transmits yellow and blue rays, while it stifles or absorbs the red. Now, as the presence of manganese contributes to the formation of a red glass, or one which transmits red rays, and absorbs the yellow and blue, the proportion of the manganese is so artfully contrived that a mixture of two coloured glasses is produced, which mutually disguise each other's defects, so that the green and the red rays combine together in the glass, and thus transmit white light. The plate-glass manufacturer sometimes allows a slight excess of manganese, in order to produce a delicate amethystine tint, which improves the complexion of persons who receive the light of day through a window. This, however, is not the origin of the tinted glass which is to be seen in the windows of some of the houses at the west end of London. By long exposure to the weather and to the action of light, the red manganese glass has in some way, which it is difficult to explain, become isolated from the green, and so far predominates, that a white window-curtain, the roller-blind drawn down, or other light object, allows the red tint to be distinctly seen from the street.

Glass is also liable to other decomposing influences, which are better understood. The glass of stables is peculiarly liable to decomposition and the exhibition of prismatic colours; but this is due to the ammonia attacking the silica. Glass which contains oxide of lead is liable to blacken on being exposed to air containing sulphuretted hydrogen; and such glass, on being heated, is liable to become black, by the reduction of the oxide to metallic lead. The action of hydrofluoric acid on glass has been noticed in the article FLUORINE.

Glass is also liable to change from what is called *devitrification*. Réaumur noticed that glass vessels buried in a crucible containing a mixture of gypsum and fine sand, and thus exposed to the high temperature of an earthenware furnace, during the burning, were deprived of their lustre and much of their transparency; the fracture was dull and earthy, but at the same time fibrous, and of a silky texture: a portion of unchanged transparent glass was generally left in the middle, towards which the fibres converged. In an analysis by Dumas of devitrified glass, a great loss of potash was noticed. Comparative analyses have shown that in a mass of such glass different chemical compounds are formed, one of which assumes the crystalline form. The devitrified state may also occur during the operations of working, in consequence of repeated heating: certain parts of the mass become opaque, and the glass too tough to be worked. The brittleness of glass, and its liability to break from sudden changes of temperature, are greatly diminished by devitrification: such glass is even less brittle than porcelain. *Réaumur's porcelain* is made of this kind of glass.

An intelligent manufacturer[2] (to whom the art is greatly indebted for a variety of improvements, and the scientific inquirer for access to the best sources of information connected with flint-glass,) arranges the various glasses known in commerce into two groups, *simple* and *compound*. Simple glasses are,—I. *Crown-glass*, which may consist of sand 5 measures, ground chalk 2, carbonate of soda 1 measure, and sulphate of soda 1. II. *Plate-glass*, which may consist of Lynn sand, washed and burnt, 400 lbs., carbonate of soda 250 lbs., ground chalk 30 lbs. III. *Common bottle-glass:* sand 100 measures, soapers' waste 80, gas-lime 80, common clay 5, rock-salt 3. Compound glasses, in addition to the above ingredients, contain certain metallic substances, in various proportions. Thus, white enamel contains arsenic, tin, or antimony, which, as well as lead, form distinct qualities of compound glasses, materially increasing their specific gravity, and acting as powerful fluxes. The metallic oxides also impart colours to glass. A highly pellucid and transparent flint-glass may be composed of the following ingredients:—carbonate of potash 1 cwt., red lead or litharge 2 cwt., sand, washed and burnt, 3 cwt., saltpetre 14 lbs. to 28 lbs., oxide of manganese 4 oz. to 12 oz. The mixtures of these materials is called *batch*, and when fused, *metal*.

Soft white enamel (opaque). To 6 cwt. of batch add 24 lbs. of arsenic, 6 lbs. of antimony.

Hard white enamel (opaque). To 6 cwt. of batch add 200 lbs. of putty prepared from tin and lead.

Blue Transparent glass. To 6 cwt. of batch add 2 lbs. of oxide of cobalt.

Azure Blue. To 6 cwt. of batch add about 6 lbs. of oxide of copper.

Ruby Red. To 6 cwt. of batch add 4 oz. of oxide of gold.

Amethyst or Purple. To 6 cwt. of batch add 20 lbs. of oxide of manganese.

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(1) Arsenious acid (AsO_3) produces the same result, taking up oxygen and becoming arsenic acid (AsO_5).

(2) Apsley Pellatt. "Curiosities of Glass-making." 1849.

Cornelian Orange. To 6 cwt. of batch add 12 lbs. of iron ore and 4 lbs. of manganese.

Emerald Green. To 6 cwt. of batch add 12 lbs. of copper scales and 12 lbs. of iron ore.

Gold Topaz Colour. To 6 cwt. of batch add 3 lbs. of oxide of uranium.

Cullet, or broken glass, may be mixed with the batch of the above glasses in suitable proportions.

The specific gravity of the different kinds of glass varies from 2·4 to 4. Flint is the densest kind of glass, on account of the large proportion of lead in it; its specific gravity varies from 3·2 to 4; plate-glass from 2·4 to 2·6.

SECTION III.—THE GLASS POTS, FURNACE, &c.

It will be seen from the above details, that the base of all glass is sand, and that an alkali is the chief solvent. In the compound glasses, oxide of lead as well as the colouring metals behave as active fluxes; such glasses, therefore, need less alkali in proportion to the sand than the simple glasses. In fusing the materials of which they are composed, and retaining them in a state of fusion, flint and compound glasses require protection from the smoke and flame, which would deoxidize the lead and other metals, and precipitate them in the metallic state; hence these glasses are melted in covered or hooded pots, sheltered entirely from the fire. Flint glass requires less heat for fusion than plate or any of the simple glasses; but the heat having to find its way through the solid walls of these glass pots, the temperature of the flint-glass furnace is higher than would be otherwise necessary. On the Continent, where dried beech or oak fuel is burnt, open pots can be used for flint-glass. The simple glasses, *crown, plate,* and *bottle,* could not be melted in a covered pot. The intense heat necessary for the fusion of these requires that the flame of the furnace should come in contact with the materials, so that open pots are used in melting them.

The *batch* or *frit* is prepared by carefully mixing the materials and sifting them through coarse sieves. It is of a salmon colour. The mixing is usually performed by hand, and is therefore imperfect, a circumstance which is likely to interfere with those chemical changes and mutual reactions of the materials which lead to the formation of a homogeneous fluid transparent body. A mixing apparatus has been contrived by Mr. Chance, for crown-glass, consisting of a chamber *a*, Fig. 1052, with an opening *b* at the top for receiving the materials, and another in the semicircular bottom, at *c*, through which the batch is removed; *d* is a cylinder on the surface of which a number of beaters are obliquely fixed. Motion is given to the cylinder, which tosses about and mixes the materials. In some cases a revolving wooden barrel is used, and is said to be the most effectual mechanical method hitherto adopted.

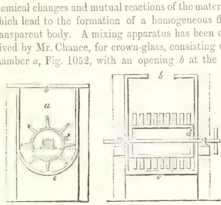

Fig. 1052.

The flint-glass-house is usually in the form of a truncated cone 60 or 80 feet high, and 40 or 50 feet in diameter at the base. In the centre of this is the furnace, which is circular in form, and in its action is intermediate between an air-furnace and an oven: round its circumference at regular intervals are the pots in which the glass is melted, and these vary from 4 to 10 in number. The grate is nearly on a level with the floor; the ash-pit, or *cave*, is a subterranean passage extending across the building, and at right angles with it are smaller caves communicating, so as to catch the wind from as many aspects as possible. There are as many flues as pots, one flue being placed between every two pots, and immediately abreast of each pot and between two flues is an aperture called the working hole, which is used for introducing the raw materials and getting out the glass. The arrangement of the furnace will be understood from the plan Fig. 1053. The coals are shovelled through a square hole A upon the grate in the centre of the furnace B: the grate bars are supported by two strong iron sleepers, and are protected from the intense heat by being previously covered with a layer of clinkers, potsherds, or broken Welsh lumps; but as the furnace attains its maximum heat, sufficient clinkers are formed to serve the purpose. A furnace for 10 pots of 36 inches diameter is 12 feet 7 inches in interior diameter; 19 feet in exterior diameter, including the flues: the height to the inside centre of the dome D is 1½ feet; each of the arches is 3 feet 1 inch wide by 3 feet 3½ inches to the highest part. The flame or smoke is not allowed to issue from the centre, it therefore escapes by the linnet holes C, below the foot of the dome, Fig. 1054, and passing up the flues F discharges into the brick dome and from thence into the funnel and chimney shaft. The fire is regulated by the *tiseur,* who can raise the heat of

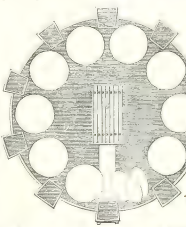

Fig. 1053. GROUND-PLAN OF THE SIEGE, FLUES, AND FIRE-PLACE OF FURNACE.

the furnace to the highest pitch by opening holes at the bottom of the grate. A ten-pot furnace consumes from 15 to 24 tons of coal per week. In addition to the principal furnace, there is also opening into the glass-house the end of a long gallery called the *leer* or annealing arch, Fig. 1066, in which the manufactured goods are allowed to cool gradually. There is also a small furnace for softening the glass during the fabrication of a vessel when too large to be heated before one of the working holes. In Mr. Pellatt's glass-house, the interior of which is shown in Fig. 1055, the pots are arranged differently to those in the plan, Fig. 1053; for instead of one large furnace, he has two small ones, both opening into the same chimney, so that while one is in full operation, the other may be undergoing repair, or not be worked at all should the trade not be brisk. This arrangement leads to considerable economy of fuel.

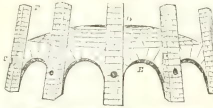

Fig. 1054. INTERIOR VIEW OF THE BRICK DOME.

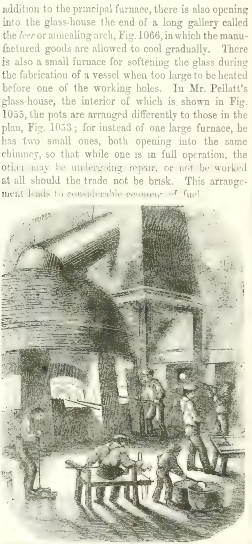
Fig. 1055. ELEVATION OF THE FURNACE AND INTERIOR OF FLINT-GLASS HOUSE.

The pots for flint-glass are hooded, and have a mouth in front. They are made of fine, pure refractory clay, free from lime and iron pyrites, and containing as little oxide of iron as possible. Stourbridge clay, which contains little besides silicic acid and alumina, is well adapted for the purpose. About one-fifth of old pots ground is used with the clay: this assists the more regular drying of the pots, and renders the whole body more porous and less likely to crack by heat. The pots are built without the use of moulds. The old and new clay are mixed together, saturated with water, and kneaded by the feet of men three times over, until the mass has acquired a pasty consistence. It is then rolled into small pieces about the size of a sausage, and these wet rolls are placed together upon a leaden slab to the thickness of 4 inches to form the bottom; the mass is then beaten with a wooden mallet, and pressed by hand. The sides are raised by pressing the clay rolls from the inside of the curve, upon the rolls previously applied, so as to exclude the air and leave the substance of the sides from 2½ to 3 inches thick. The dome is continued in the same manner, circle upon circle, diminishing towards the centre. When the pot thus formed is sufficiently hard, the mouth is cut open and finished. Experience has proved that kneading by the naked feet is better than by a pug-mill or machinery. The clay is kneaded in a room of uniform temperature, not below 55°, nor above 80°, as it is not desirable to dry the pots too quickly. The pots are left to dry or ripen from 4 to 6 months. When sufficiently dry, they are removed to a hot room of from 100° to 150°. Before setting in the furnace a pot is annealed in the arch, where it is kept for a week or more, and gradually raised to a white heat. The flint-glass pots, Fig. 1056, will contain about 18 cwt. of melted glass: they measure 3 feet external diameter; they are 3 feet high to the filling part, and weigh about 10 cwt. The horse-shoe-formed piece shown in Fig. 1056 is used for contracting the mouth of the pot. For coloured glass, 3 small pots, 2 side by side and 1 above, as in Fig. 1057, are used in melting, and the 3 fill up the same space in the furnace as that occupied by one large pot.

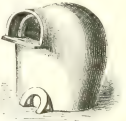
Fig. 1056. FLINT-GLASS POT.

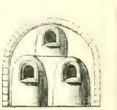
Fig. 1057. COLOURED GLASS POTS.

The setting of a new pot is a very arduous undertaking. It is generally performed at the end of the week, when the work of the glass-house is slackened. All hands are required to be present, absentees, except from illness, being fined severely. The Editor witnessed the operation a few years ago, and described it in his work on the Useful Arts: the following, with a few additional particulars, is taken therefrom. The first part of the process was to get out the old pot, which had done duty for seven months, but was now rendered worthless from having "sprung a leak." The heat of the glass-furnace is sufficiently intense to an unpractised looker-on, during the ordinary operations of glass-blowing, &c., when the fire is covered up by badly conducting materials, with the exception of a few apertures for getting out the glass and heating the tools, &c.; but now the wall of one of the arches was to be taken down, thus exposing the men to the naked heat of a huge furnace. The men were about 24 in number, 2 or 3 of whom worked at a time, and were frequently relieved.

The difficulty of getting out the old pot was very great, owing to the firm hold which it had on the floor of the furnace: it was in fact cemented to its *siege* by the glass which escaped from the crack whereby it was rendered useless; and this cementing glass became more and more difficult to loosen, as the current of air which rushed towards the now large opening solidified the glass. The men, therefore, had to work at the bottom of the crucible with a large iron bar, steeled and sharpened at the point, placed across another bar or roller as a fulcrum, and resting their weight at the end of this long lever endeavoured to loosen the pot. Six or eight other men were also furnished each with a bar about 5 feet long, like a javelin, steeled and sharpened at one end; these rushed forward, guarding their faces with their upraised arms, and aimed a blow at the rocky incrustations on the siege. By such means large pieces of glass, soiled and blackened by the ashes of the furnace, were brought away, together with fire-brick, masses of clay, and sometimes pieces of the pot itself. The men who worked the large bar gave a few blows, and then retreated from the fierce heat, to be succeeded by two or three others, who in like manner performed their brief but arduous task, and then retreated to the shelter furnished by the massive wall of the furnace.

At length, the pot being loosened all round, its base was elevated by crowbars, and a low iron truck moving on two wheels thrust under it, and thus it was withdrawn and thrown aside at some distance. The floods of heat which now radiated from the opening were terrible: before this, the side of the pot nearest the opening, by its contact with the air, had cooled somewhat, and served, to some extent, to keep off the full glare of the furnace; but now there was no shield—no defence. And here was, perhaps, the most arduous part of the operation; the siege, or platform, slightly raised above the floor of the furnace, was to be repaired to receive the new pot; for this purpose, the most fire-proof workman was selected: he was furnished with a kind of shovel, with a handle 14 or 15 feet long resting on the roller before noticed; a number of men stood by, each holding a lump of kneaded fire-clay; one of these men, as he was directed by the foreman, went up to the mouth of the opening, and placing his lump of clay on the shovel, quickly retreated; the clay was then deposited on the siege, and worked quickly with the spade; a second man advanced with a second lump, which in its turn was made to fill up some irregularity in the siege, and thus piece after piece was deposited, until a tolerably even bed was produced. Meanwhile, another party of men were ready with the iron truck at the annealing oven, the doors of which were at a given signal thrown open, showing the pot glowing at a bright red heat. To thrust the projecting bars of the truck into the mouth of the new pot and bring it out, was the work of a moment: it was quickly wheeled to the furnace, deposited in its place, and being held by crowbars, the truck was removed, the whole being accomplished with a dexterous celerity which pleased and satisfied the looker-on. The next part of the operation was to close up the opening, for which purpose two heated masks of fire-clay were brought on shovels: these rose from the ground about a yard high, and upon them were placed bricks and fire-clay. The mouth of the pot being stopped with a temporary screen of clay, the rest of the opening was closed up with great despatch by a number of men, each bearing a portion of clay, or a brick, which he knew precisely where to deposit. The operation thus concluded occupies three or four hours, and is one of great fatigue, excitement, and even danger. The necessity for this operation may not occur for months, but when it does, not more than two pots can be set in the same week, for if more were attempted, the furnace would get too cold, and endanger the setting of the glass in the other pots. Good pots last about three months each; some will last above twelve months, but they wear thin at the back, and endanger the loss of the glass by bursting. The pots are occasionally patched up with clay in front, in the crown, and sometimes at the bottom. When they crack in front, a leak is prevented for several weeks by exposing the crack to the air, and as the glass oozes out, it solidifies and stops it up; or cold water is thrown on it for the same purpose, or a piece of black glass, or of bottle metal, is softened by heat, and plastered on.

The new pot, having safely passed through all this severe treatment, has to undergo a still more serious test. "Will it hold glass?" is the anxious inquiry of the manufacturer. *Cullet*, or broken glass, is first thrown in, and spread over the sides in a melted state; this forms a vitreous glaze, which penetrates to the depth of a few lines into the substance of the pot, and forms a hard glass difficult of fusion, which protects the pot from the further action of the materials.

The raw materials, thoroughly incorporated with from one-fourth to one-third of their weight of broken flint glass, are introduced by means of a clean iron shovel into the melting-pot, which has been raised to a white heat. The pot is filled, the temperature is raised to its maximum, and as the mass subsides by melting, a fresh quantity is introduced, until it is filled with melted glass. The mouth is then closed with a stopper, and luted, leaving only a small aperture at bottom. The glass does not become transparent for some time, the opacity being due to the lime and earthy impurities which do not fuse. The heavier of these subside, but the greater part rise as a scum, called *glass-gall*, or *sandiver*, which is skimmed off through the aperture: if not removed, it would pass off in a dense vapour, which would injure the dome of the pot. It should, however, be remarked, that in flint-glass works the materials selected are so pure, and in such good proportion, that there is little or no impurity to be removed; and if an excess of one material be found, it is corrected in the next batch. During the melting, or *founding*, the stoker, or *teazer*, keeps the furnace well supplied with fuel, to prevent any part of the grate being uncovered, as a rush of cold air from the cave would probably split the pots. The founders (Fr. *fondeur*) watch the progress of the fusion by taking proofs, or drops, from the pots on a short rod, flattened at one end, and they examine whether any grains of sand remain undissolved, and whether the air-bubbles (called *seed*) have disappeared. During the *boil*, or escape of carbonic acid, the mass is in a state of agitation, which greatly facilitates the escape of air, and answers the purpose of stirring. In 40, or 48 hours after charging, the vitrification is complete. When the sandiver becomes transparent and colourless, the temperature of the pot is lowered by diminishing the draught, in order to bring the glass from a state of perfect fluidity, in which it could not be worked, to that free plastic condition necessary for working. But as the working-heat of the furnace must be constantly maintained night and day, the arrangements of the glass-house are generally so contrived, that the pots shall contain enough metal to last out the first four working-days of the week; the men working incessantly night and day in gangs, relieving each other every six hours. By Friday morning, or evening, the pots are so far emptied, as to require re-filling; or a new pot is to be set, as already noticed.

SECTION IV.—FLINT-GLASS.

In the working of flint-glass we see the peculiar properties of this most beautiful material strikingly developed by heat, such as its extreme plasticity, ductility, and flexibility, so that it can be blown, moulded, turned, and cut with scissors into every variety of form. It may be blown so thin as to float about in the air, and its ductility is such that a small lump can be drawn into a thread several hundred feet in length in one minute. The fine filaments of spun glass have been interwoven with silk and other fabrics, with beautiful effect. At common temperatures, glass possesses but a small range of elasticity, but according to Mr. Pellatt, hollow glass balls are so elastic, that if dropped from a height of ten or twelve feet upon a solid polished anvil, they will rebound to half or one-third of that height, and generally without fracture, until after the second rebound. In the ordinary state, glass is not malleable, nor do any vitrified bodies appear to be so.

The property of welding by contact at a red heat or thereabouts, is also one of the valuable properties of glass, whereby it enables parts to be joined together by mere contact, and handles, feet, rings, &c. to be attached. The welding is perfect at the points of union, unless, indeed, a sulphurous or carbonaceous film interpose, and this, however thin, will cause the cohesion to fail.

The property of glass to fracture under the contraction caused by a sudden chill, enables the glass-blower to separate pieces of glass with ease and expedition. The two operations of welding by contact and separation by contraction, are the most important in the manipulations of the glass-blower. The tools used by him are few and simple, and have continued in use, unaltered, for more than 200 years; his tact and skill more than supply the place of mechanical aids. The *blowing-tube* is of iron, from 4 to 5 feet in length, with a bore of from $\frac{1}{2}$ to an inch in diameter. It is smaller at the mouth end than at the other end, which gathers the metal. The *ponty* or *pontil* is a solid rod, used to support the glass while working, when the blowing-rod is no longer needed. Both these rods are heavy or light, according to the nature of the work. The *pucellas*, B, Fig. 1058, made something like a pair of spring sugar-tongs, the prongs resembling the cutting parts of shears, but blunt, are used for rubbing the outside of solid or hollow glass, and pressing it into a smaller diameter, at the same time elongating the parts by rotation. This tool is also used to open or close the insides of hollow vessels, and to shape the glass as it is rotated on the inclined planes of the chair in which the workman sits. The *spring-tool* A is a species of tongs for laying hold of half-formed handles, and for seizing the glass while making. The *shears* D are strong scissors for cutting off the surplusage of glass handles, and for levelling the edges of bowls of wine-glasses, &c. "Much skill is required to shear a wine-glass. It is held upon the iron by the left hand, and rotated towards the shears, which are grasped in the right hand of the workman. A well-skilled workman can shear a glass entirely round the bowl at one operation. In Bohemia and Germany, generally, the workmen are said not to be sufficiently skilful to use the shears; but the edges of bowls are blown in the rough, and cut smooth by the glass-cutter when cold, which leaves a flat and unsightly finish, far inferior to the round smoothed edge of fire-polish after shearing." The *battledore* E of wood is used for flatting glass, as will be explained presently. The glass-blower is also furnished with *compasses* and a *measure-stick*. The *marver*[1] is a slab of cast-iron about an inch thick,

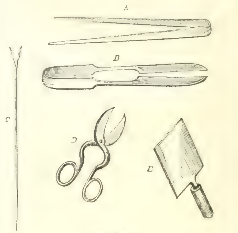

Fig. 1058.

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(1) From the French *marbre*, a *marble* slab being formerly used

with a polished surface, supported by a wooden stand. Upon this slab the glass is rolled to give it a regular exterior surface, so that on expanding it by blowing, a

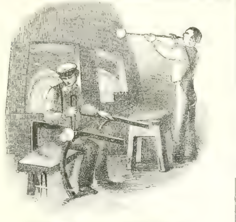

Fig. 1059. THE GLASS-MAKER'S CHAIR.

uniform thickness is produced. The *glass-maker's chair*, Fig. 1059, is a flat seat of wood about 10 inches wide, each end of which is fixed to a frame connected with four legs and two inclined arms, upon which is screwed an edging of wrought-iron for rolling the blowing-iron with the hot glass backwards and forwards with the left hand, while the pucellas, held in the right hand, give the glass the required form. The finishing and intermediate shaping depend chiefly on the application of centrifugal force by rapid hand rotation with the blowing-iron, and upon the expansive force of air in widening the forms while being reheated at the aperture of the furnace, technically called *flashing*, and upon a skilful final throw.

A visit to a glass-house will convey a much more vivid idea of the beautiful art of the glass-blower, and admiration for the wonderful material with which he works, than the most elaborate written and pictorial descriptions. In the absence of this, the following examples from Mr. Pellatt's work may be of use. The first will explain the method of manufacturing a goblet, and nearly all vases or articles having three pieces, viz. a bowl, a stem, and a foot.

The blowing-iron being heated, at the end, nearly to redness, is introduced into the pot of metal, which instantly adheres to it, and by turning it round, the workman can *gather* up as much metal as he requires. If a large quantity be wanted, the first gathering is taken out and cooled by exposure to the air, and when the lump is somewhat consolidated, another gathering is made upon it, and even a third, or a fourth if required. These gatherings increase in cubical proportions, the first being usually about 8 ounces, the second 4 lbs., and the third 16 lbs. For a wine-glass, however, a first small gathering suffices, and this is represented in *a*, Fig. 1060, in the form of a ball of hot glass adhering to the blowing-tube. This having been rolled on the marver, and expanded a little by blowing, assumes the form of *b*, which being further shaped for the bowl of the wine-glass, and flattened with the battledore, is brought into the form of *c*. A solid ball is then attached to the flat part of the bowl, as shown in *d*, and from this the stem is to be lathed or shaped by the pucellas while it is being rotated up and down on the inclined planes of the glass-maker's chair, which serves as a lathe. The stem thus shaped, as at *e*, is ready to receive the foot. The moment the glass gets hard by cooling, the rubbing of the pucellas must be discontinued, or an excoriated surface will result. *f* has a globe attached to the stem, which is afterwards opened, and flattened by the pucellas into a foot, while being lathed and rapidly rotated, as *g*, on the arms of the chair. A boy now gathers a small knob of glass upon an iron pontil, and attaches it to the foot, as at *h*. The blowing-iron is then wetted off at the dotted line in *h* by the touch of the cold pucellas, which cracks the glass, and it is disengaged by a smart blow of the pucellas. In *i* the bowl is under the operation of shearing, so as to make it perfectly even, and fit for the flashing and finishing. The finished glass *k* is then knocked off from the end of the pontil by a sharp blow, and carried by a boy to the annealing arch, on the end of the forked rod c, Fig. 1058.

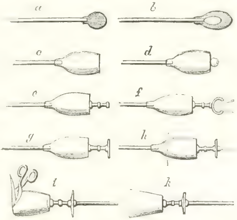

Fig. 1060.

A ringed decanter is made in the following manner: The gathering is shown at *a*, Fig. 1061; this being

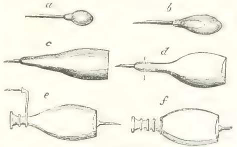

Fig. 1061.

slightly distended, the workman swings the blowing-iron wholly or partly round, and the glass yielding to the centrifugal force, assumes the form of *b*. It is further expanded and battledored at the end, as shown at *c*; it is next formed into *d*. The pontil is then attached to the bottom, *e*; the blowing-iron wetted off at the dotted line, and the mouth warmed up and shaped. Another workman then gathers upon a pontil a small piece of glass, which is dropped on to the part where a ring is required, as at *f*. By rotating the decanter, the entire circle or ring becomes welded by contact, and its surplus is tapered, and torn suddenly away. The whole is re-heated, and the pucellas are then pressed upon the ring of the decanter, while rotating upon the inclined plane of the chair. Pucellas for forming rings differ from the common tools in having two dies affixed to the prongs, which being pressed upon the ring while hot, give the required shape and size after re-heating the decanter. A second and a third ring are then added, as at *f*. The ponty is next rotated on the incline, and the brim finished: the rings are also well melted in to ensure safe welding and annealing.

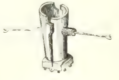
Fig. 1062.

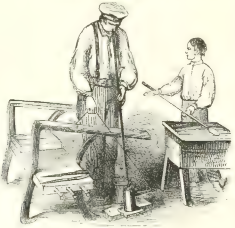
Fig. 1063. MOULDING BOTTLES AND MARVERING.

Flint-glass bottles are formed by moulding. The mould is made of brass. That represented in Fig. 1062 is termed an *open and shut mould*, and is generally constructed in two exact halves, connected with a bottom hinge. This form of mould produces in a round bottle two seams or lines, caused by the two sides of the mould not shutting quite closely. The seam is not unsightly in the square form, as the joint falls into two of the angles; the mould being separated in the line of the diagonal. The following is the process for making eight-ounce phials. The man collects upon the end of his blowing-iron a quantity of melted glass sufficient for one bottle; then, holding the rod vertically for a moment, he gives it a slight jerk, the effect of which is to lengthen out the lump. He then marvers it, pinches the upper part with pliers to form the neck, and placing the hot glass in a brass mould formed in two halves, (which are kept open by a spring,) he pulls the two halves together with a string, as in the figure; then blowing down the tube, the plastic glass forms, as it were, a thin lining to the mould, and assumes its internal form. On relaxing the string, the mould falls asunder, and the phial is taken out adhering to the tube. It is wetted off, and taken up on the end of a pontil by another workman, who softens it in the flame issuing from a hole in the furnace. At Mr. Pellatt's works, a small separate furnace, called the *little go*, is used for this purpose. The workman finishes it off with great rapidity; when it is conveyed to the annealing oven. The mould must be kept hot during the operation, for which purpose two blowers usually work with one mould, one man collecting and marvering his glass, while the other is engaged in blowing it out.

The seam down the body is avoided by the use of an improved mould, invented by Mr. Pellatt. The body of this mould, c, Fig. 1064, is in one piece, the neck *n n* in two pieces, which, of course, produce two slight seams. These two pieces are kept open by a spring, *s*. When the expanded ball of metal at the end of the blowing-iron is placed in the body, the two halves of the neck are brought together by the guide *g*, connected with the treadle *t*, which is pressed down by the foot. The man then blows down the tube, and on raising his foot, the counterweight *w* falls down: the two neck-pieces fly open, and the bottle is taken out.

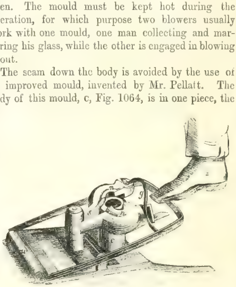

Fig. 1064. BOTTLE-MOULD.

Annealing. Referring to our article ANNEALING for the theory of this curious process, we need only here remark, that the particles of melted glass in a fluid state, exhibit a tendency to arrange themselves in a regular manner, so as to form crystals. When the glass is quickly cooled, no time is allowed to the the semifluid mass to follow this tendency, and the particles are forced to remain in that relative position towards each other which they assume during the working; or in other words, the particles are forced to form an amorphous mass. This forced relative position of the particles is greatest when the glass has been rapidly cooled; but the interior of the mass is not so subject to it as the surface, which also contracts in a greater degree. The outer layers are therefore in a state of tension compared with the interior; and this want of uniformity in the attractions of the particles for each other, causes the force of cohesion in the mass to be destroyed by a slight external impulse. This strained or forced condition of the particles is relieved by subjecting them to a temperature sufficient to allow them mutually to readjust their relative positions, and to fix them in what

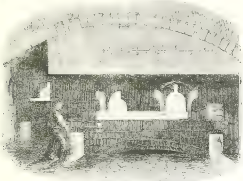

Fig. 1065. THE ANNEALING-ARCH.

may be called a natural amorphous state, by gradually letting down the temperature. For this purpose, the glass articles, as they are shaped and finished by the blower, are put into a lear at the receiving end or side nearest the glass furnace, where the temperature is just short of the melting heat of glass. Small articles are arranged on iron trays, which are gradually pushed forward by the trays last put in towards the discharging or cooler end of the furnace, which terminates in the chimney. The lear consists of from two to four cylindrical arches placed side by side. Coke is the fuel, and the annealing lasts from 6 to 60 hours, according to the weight of the articles. The hotter the goods enter the arch, the better. Large goods receive a final re-heating at the mouth of an empty pot called the *glory hole*. The proper direction of the wind is a point of importance. It ought to pass from the fuel of the lear towards the chimney; a contrary current causing much loss from breakage. Goods for cutting require extra care and time in the lear. They may be protected from the cold draught by iron covers called *[illegible]*, or by being buried in sand. In some cases thick glasses are annealed in kilns, *i.e.* spaces entirely shut up, and heated, so that there is no draught or circulation of air within. The lear is furnished with cast-iron doors for opening or contracting the mouth.

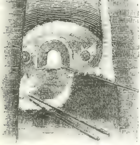

Fig. 1066. THE GLORY HOLE.

Articles in flint-glass may be cheaply and rapidly formed by an operation called *pressing*; for which purpose a die is secured by a ring and handle, and the glass being gathered and dropped into it, a matrix or plunger is brought down by a lever, and presses the soft glass into the required form of the article. The great difficulty is to gather the exact quantity of metal; for if it be in excess, the article is thickened; if not enough to fill the mould, the article is spoiled. In order to get a polished surface on pressed glass, the moulds must be kept at an equable temperature, a little short of red heat. If too hot, the outer die will adhere to the glass: if not hot enough, the surface will not be clear and transparent. Drops for chandeliers are *pinched* in twin brass dies attached to handles, as in Fig. 1067. The dies are pro-

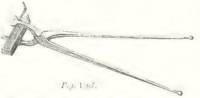

Fig. 1067.

vided with steel wires, which pierce the holes for the brass wires by which the glass drops are united to form the chandelier. Lumps of glass made expressly for drop-pinching, when softened in a blast-furnace, can thus be moulded. Arms of chandeliers are also pressed by twin dies, the upper die being fixed to the plunger, and the under one to the bed of a powerful lever press, the metal being gathered as usual, and the power of the press applied. By this method the crude form only is given to arms and drops. They require cutting and polishing on a lead lap, to produce the required brilliancy.

In the Great Exhibition were chandeliers with ruby drops, and others with drops of different colours. Never was there a greater mistake in art manufacture, than to lower by any means the diamond brilliancy of the brightest and purest flint-glass; for where the light passes through a coloured medium, there must be absorption of certain rays, and a consequent loss of light and brilliancy. We have not

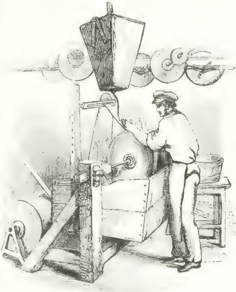

Fig. 1068. THE GLASS-CUTTER'S WHEEL.

seen the coloured chandeliers lighted up by night, but we have no doubt that they look much better by daylight; whereas the contrary ought to be the case.

Glass-cutting, or grinding, is performed in the following manner. A cast-iron wheel is made to revolve in a lathe, and above it is suspended a hopper containing sand and water, which continually pours in a thin stream upon the rim of the wheel. On applying the glass to this rim, it is ground away by the action of the wet sand. The rough sand-marks are smoothed out by a stone wheel with water, which prepares it for polishing; this is effected by means of a willow-wood wheel, first with a mixture of pumice and rottenstone, and the finishing is performed by the same wood wheel or lap with putty-powder. Engraving on glass is performed in the same manner as SEAL ENGRAVING. Glass may be drilled or turned on a small scale simply by using oil of turpentine with the common drill, file or turning-tool. If care be taken that the cutting edge is never left dry, it will not soon blunt, and the glass can be worked with great expedition.

Among the varieties of flint-glass must be mentioned *Strass*, (so called from the name of its German inventor,) used in the manufacture of fictitous gems. It has a remarkable lustre; it contains more oxide of lead than flint-glass, and in some cases a small proportion of borax. Rock crystal is used instead of sand for some varieties of strass, and for those glasses which are employed as pigments by glass-painters. The materials for strass must be very pure, and when well made, it is a successful imitation of the diamond. The addition of metallic oxides gives various imitations of precious stones. In the French department of the Great Exhibition, some of these were so successful as not to be distinguished from real gems, and no less an authority than M. Bontemps declares that their inferiority consists only in their comparative softness and consequent deterioration by wear. In the English department, Mr. Pellatt, among his other admirable illustrations of the manufacture, had a model of the *koh-i-noor*, made of a highly refractive and dispersive strass, rivalling the diamond itself. Being mounted so as to resemble the original, this model forms an elegant drawing-room ornament.

According to M. Donalt Wieland, an excellent strass may be obtained by one of the following recipes:—

	No. I.	No. II.
Rock crystal, ground	4056 grains	3456 grains
Red lead	6300 ...	5328 ...
Pure carbonate of potash	2154 ...	1944 ...
Borax	276 ...	216 ...
Arsenic	12 ...	6 ...
	No. III.	**No. IV.**
Fine white sand	— grains	3600 grains
Rock crystal, ground	3600 ...	—
Pure white lead	8508 ...	8508 ...
Pure carbonate of potash	1260 ...	1260 ...
Borax	360 ...	360 ...
Arsenic	12 ...	—

The lustre and density of the glass are increased by a tranquil and prolonged fusion, which should be continued for 24 hours.

SECTION V.—OPTICAL GLASS.

The progress of the beautiful science of optics has been to a certain extent impeded by the defects of the flint-glass used in certain instruments. Science requires a perfectly homogeneous glass, of the same density and composition throughout its mass. This it is very difficult, if not impossible, to obtain. The best flint-glass is liable to such defects as *striæ* or *wreath*, *knots*, *threads*, and *tears*. The striæ consist of undulatory appearances, resulting from a want of uniform density in the glass, so that the rays of light, in passing through it, are refracted and dispersed in different directions, thus producing a wavy effect, not always, indeed, apparent to the eye, but painfully evident when such glass is applied to the construction of an optical instrument. Flint-glass is more subject to this defect than any other kind. Knots are opaque particles of earthy matter from the furnace, or abraded from the glass-pot; or they may consist of particles of glass-gall, or imperfectly vitrified grains of sand. Threads and tears consist of partially vitrified clay from the roof or glass-pot, not uniformly mixed with the glass, and being different in colour, and in their expansion and contraction by heat, dispose the glass to fly to pieces without any apparent cause. The want of clearness arising from minute bubbles (*seed*) diffused through the glass, in consequence of its not having been kept in a sufficiently fluid state, has been already adverted to. All these defects, with the important exception of striæ, can with care and attention be got rid of in the manufacture of *crown* glass, and in this case, where the materials do not differ greatly in specific gravity, striæ are of less importance. In flint-glass, however, where the materials vary so much in density, it is difficult to obtain a disc of homogeneous glass a few inches in diameter, such as is required for a lens, the correct action of which depends more on the equal density or refractive power of the glass than on whiteness or brilliancy. If the raw materials be not well incorporated, a pot of glass is apt to have an excess of oxide of lead in some parts, and a deficiency in others, leading, of course, to different densities in different parts of the mass. In slowly cooling a pot of uniform glass, the heavier silicate of lead always subsides, while the lighter alkaline silicate is found in excess above. If, to prevent this separation of the two silicates, the pot be rapidly cooled, the glass becomes too brittle. Want of uniformity in the glass arises from the unequal heating of the pot in the furnace, in which the sides are more heated than the bottom. It has been proposed so to construct the furnace as to allow of heat being applied below the pot, in order to expand and diffuse the denser glass. Agitation is supposed to be favourable to the production of a uniform glass; and it has been proposed to ladle the glass from one pot to another, or to stir it up with a rod of iron, cased in stoneware, to prevent the naked iron from colouring the glass. After agitation, the pot is to be left quiet for a short time, for the air-bubbles to disperse, and, when the glass is *fine*, it is to be cooled quickly, or gathered out on the end of a rod. If the pot be cooled, the mass is broken up by a hammer into conchoidal lumps, to which a lenticular shape is given by raising them to a dull red heat in a reverberatory furnace. The mass may also be cleaved while cooling, so that the fracture may follow the direction of the faulty parts. It is said that masses of homogeneous glass of 10 lbs. weight have thus been obtained.

For many years, English flint glass, with about 10 per cent. increase of lead, and of the sp. gr. 3·25 to 3·35, technically called *heavy glass*, was used for telescopes at home and abroad. It was worked in the following manner, as described by Mr. Pellatt:—A ladle in the form of a sugarloaf, about 5 inches in diameter and 7 inches deep, is dipped carefully into the metal, which has been previously skimmed: when filled, it is taken out of the pot, and suffered to get partially cool: to the large end of the sugarloaf-shaped piece of glass thus produced, a glass-blowing iron with a hollow disc is welded, and placed to the opening or mouth of the pot for re-heating. When sufficiently soft, it is blown into a muff or cylinder: the end furthest from the blowing-iron is cut off; the cylinder is flattened into pieces or plates of 14 inches in length, and 10 inches in width, and about half an inch in thickness, and annealed: after which the plates are sold to the optician, for cutting and grinding into discs.

Many years ago, M. Guinand,[1] a clockmaker, of Brenets, near Neufchatel, in Switzerland, succeeded in producing flint-glass exempt from striæ, by some method of rabbling or stirring up the liquid glass before cooling. In consequence of this, which may be regarded as the first successful experiment in the production of optical glass, Guinand was invited to Bavaria, where, in conjunction with Frauenhofer, he made a number of object-glasses, the largest of which, 9 inches in diameter, was used in the telescope at the observatory of Dorpat. After his return to Switzerland, Guinand sent some small discs of his flint-glass to the Astronomical Society of London, and, some time after, a disc of 6 inches in diameter, which at that time was considered a rarity. A committee, composed of Messrs. Dollond, Herschel, and Pearson, reported favourably thereon: but Guinand's negotiations with the Society did not lead to any decisive measures, and his proposals to the French government were equally fruitless. The Astronomical Society of London appointed a committee, consisting of Messrs. Herschel, Faraday, Dollond, and Roget, for the purpose of making experiments on the manufacture of optical flint-glass. Dr. Faraday conducted the experiments, and Mr. Pellatt liberally placed at the service of the commission the resources of his glass-house, and his own large experience. The result of this inquiry was the production of a glass of remarkable purity, consisting of a combination of silicate of lead with borate of lead: the materials were perfectly pure, and vitrified in a platinum crucible. If the air-bubbles are slowly disengaged, a little spongy platinum is thrown in, in fine powder, and the glass stirred with a platinum spatula. The powder subsides, and the glass may be poured off quite clear and free from striæ. This highly refractive and dense glass has been of assistance to Dr. Faraday in his physical researches, but has not answered the purpose for which it was originally intended, on account of its gradual decay.

Optical glass continued to be made in Bavaria according to Guinand's method, but its production was confined to a working optician, M. Mertz. Guinand, shortly before his death, also revealed his secret to his wife and his two sons.[2] One of the latter sold the secret to M. Bontemps; but, on attempting to apply it, it failed;[3] whereupon, the contract was broken. But M. Bontemps, considering with great fairness that the principle of the method had been disclosed, and only required study and experiment to carry it out, associated himself with the younger Guinand, and at length, in 1828, succeeded in producing good optical glass, one disc measuring 12 inches, another 14 inches, and a number of others of smaller dimensions. After this, the Guinands continued for some years to manufacture optical glass on their own account: they disposed of the secret to M. Daguet, of Soleure, who sent to the Great Exhibition discs of flint-glass varying from 4 to 15 inches in diameter, and of crown-glass, from 4 to 6 inches. When subjected to the severe test of polarized light, some discs of crown glass were found to be not quite uniform in density. The higher temperature required for the fusion of crown glass is one reason why it is so difficult to make discs of large size in this glass.

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(1) An interesting memoir of this remarkable man was read before the Society of Physics, &c. of Geneva, 19th February, 1823, and is translated in the Quarterly Journal of Science, vol. xix., published in 1825.

(2) Guinand died in 1823. In 1815 he produced several telescopes of large size and remarkable excellence. They are described as "the work of an old man of upwards of seventy, who himself manufactures the flint and crown glass which he uses in their construction, after having made with his own hands the vitrifying furnace and crucibles; who, without any mathematical knowledge, devises a graphic method of ascertaining the proportions of the curves that must be given to the lenses, afterwards works and polishes them by means peculiar to himself; and lastly, constructs all the parts of the different mountings, either with brass or other metals, casts and turns the pieces, solders the tubes, prepares the wood, and compounds the varnish."

(3) According to Mr. Pellatt, the following was the process adopted:—

"A long hollow cylinder or sheath of fire-clay, closed at one end, with a bore sufficiently large to admit of a strong blowing-iron, was brought to a red heat, and introduced into a pot of melted glass. This agitating-iron had a long handle, with a flat ring, or hand-guard, which rested when in use upon the shoulders of the pot. It was then introduced into the fire-clay cylinder or sheath, and when the metal was at its utmost intensity of fusion, the mixing began, and continued for many hours, until the operator presumed the striæ were dissipated; then, by gradually reducing the heat of the furnace, the glass became too stiff for agitation, and the pot and its contents were annealed in the furnace. Crown glass will not allow of so many hours' intense fusion and agitation as flint glass, owing to its liability to devitrify. M. Bontemps does not assert that he always succeeded in the stirring system for flint-glass. He sometimes found hard masses of small cords, as it were, linked together: these he thought were caused by the chemical action of the glass upon the fire-clay cylinder and pot; but they spread in the operation of cooling. . . . He recommended that an entire pot of flint metal, fused upon the agitation system, should be emptied upon an iron table, and cast the same as plate glass."

If we attempt to lower the point of fusion by varying the composition, the glass then becomes so attractive of moisture as to be worthless as an object-glass. If, on the other hand, we attempt to make a very *dry* glass, there is a liability to crystallization and devitrification in the cooling.

M. Bontemps[1] is said to have overcome the difficulties of the manufacture of optical glass: he exhibited in 1851, discs of flint-glass 29 inches in diameter, and of crown-glass of 20 inches, and others of smaller size, which, are said to pass satisfactorily through the ordeal of polarized light, thus showing them to be of the same density throughout. The 29-inch disc, however, presented a few striæ near the surface, which, it was thought, would be ground out in giving the lens its curvature. These glasses were from the works of Messrs. Chance, who had engaged M. Bontemps to superintend this department of their large and varied establishment.

After this long detail, the reader will probably expect us to describe the process of making optical glass. We regret to say that we are unable to do so: it is still a secret confined to the few whose labours suffice to supply the demand for large lenses. The circumstance of a very limited demand is a good reason why the possessors of the secret have been able to retain it so long. If optical glass were required in the large quantities in which other descriptions of glass are manufactured, there cannot be a doubt that its production would soon become one of the common operations of the glass-house.

Mr. James Nasmyth proposed, in 1847, a method of making optical glass, which promised well, but it does not seem to have been followed up. Supposing the materials to be pure and in due proportions, and that the vitrification is perfect, he reasonably supposed that the variations in density arise from removing the glass from the melting-pot while in the fluid state. He therefore proposed to place a large pot of the most perfectly composed glass in the furnace, and to subject it to the highest degree of heat which it can stand, in order that, by rendering its contents as completely fluid as possible, the particles may arrange themselves in strata of perfect homogeneity and uniformity of density. In order to ensure this result, this high temperature is to be kept up for at least three days. A slight variation in density will be found in the top stratum of glass, as compared with that at the bottom of the pot; but the variation of the successive parallel strata would be so gradual, that one would not vary from another in any appreciable degree. The pot is then to be left perfectly quiet, and the furnace allowed to die out gradually, taking care that no draught have access to it, or any irregularity take place in the decrease of temperature. The cooling may thus require about twenty days. When the pot is cold, the glass is to be removed, and cut into slices parallel to its top surface, by the simple means employed by marble-cutters. The result would probably be a series of discs of absolutely perfect glass. Mr. Nasmyth has tried this method on a considerable scale with crown-glass with perfect success; masses of the most splendid glass having been obtained, to all appearance perfectly free from striæ or other irregularity.[2]

This ingenious method is evidently inapplicable to flint-glass: the long-continued application of heat would dissipate its alkali, and the long repose would cause the lead to subside, so that no two horizontal layers, however thin, would possess the same density. Mr. Simms, the eminent optical instrument maker, states, that in only two instances has he succeeded in making unexceptionable object-glasses of English flint-glass, and these had only 3½ inches aperture. The flint-glass as hitherto obtained from the Continent, in discs of from 4 to 9½ inches diameter, is very costly; and the risk of its not turning out well after the labour of grinding has been bestowed upon it, has deterred the instrument-makers generally from making so costly an experiment. It is therefore to be hoped that Messrs. Chance will be encouraged in their undertaking, so important to the interests of science; and it is interesting to learn from Mr. Simms that, so far as he has tried it, their optical flint-glass is equal to the very best that was prepared by the elder Guinand.

SECTION VI.—CROWN-GLASS.

The glass commonly used for window-panes is a silicate of soda and lime: it is more difficult of fusion, and less easily worked, and much harder than flint-glass, and hence does not well admit of being shaped into vessels, or ornamented by cutting and grinding. Crown-glass is manufactured in the form of flat discs or *tables,* 52 inches in diameter. At the Great Exhibition, Messrs. Chance displayed some tables 66 inches in diameter.

The arrangement of the crown-glass furnace is similar to that of the flint: it is arranged in the centre of the cone, and contains from four to six pots, each of the capacity of half a ton. These pots are open at the top, not hooded as in the flint-glass pots. There are several subsidiary furnaces adjoining or round the inside of the cone; also an annealing furnace, or *arch,* and an oven for annealing the glass-pots before they are set. The *fritting* furnace, called *colcar,* from the French *calquaise,* is reverberatory in its action, and is used for calcining or *fritting* the materials before they are placed in the glass-pots for vitrification; the object being to effect a partial union between the silicic acid and the alkaline bases, so that the latter may not be volatilized in the furnace; this alkaline vapour not only being a positive loss, but acting injuriously on the pots and sides of the furnace. The other furnaces are used for softening the glass while passing through the successive stages from a globe into a flat table:—the *blowing furnace,* used to facilitate the blowing of the glass into a large globe, the *bottoming hole,* the *nose hole,* and the *flashing furnace,*—the use of which will be explained presently.

The materials consist of fine sand, chalk, soda-ash or crude carbonate of soda, or salt-cake, which is dry

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(1) This gentleman published, in 1852, an interesting "Examen des Verres, Vitraux, Cristaux, composant la Classe XXIV. de l'Exposition Universelle de 1851."

(2) Memoirs of the Royal Astronomical Society, vol. xvi. 1847.

sulphate of soda; also a little charcoal, black oxide of manganese, arsenious acid, and occasionally a little oxide of cobalt, to correct any defects in colour arising from the presence of oxide of iron. As the soda is liable to considerable fluctuations in its value, no fixed proportions of materials can be agreed upon, and the manufacturer has to determine the amount of real alkali in every fresh supply of ash. When all the alkali is soda-ash, the usual proportions are, 100 parts quartz sand, 35 to 40 chalk, a quantity of soda-ash containing about 8 parts soda, and from 150 to 200 old broken glass, or cullet. The proportion of arsenious acid and manganese can only be ascertained by trial. If the materials are to be calcined, they are put into the colcar, and well stirred with iron paddles and rakes, to expel water and burn off carbonaceous matters, as also to drive off carbonic acid from the chalk, and to unite the base of the alkaline carbonate with silicic acid, displacing the carbonic acid, and thus prevent the alkali from being volatilized in the glass-pot. The temperature of the colcar is gradually raised during three hours, and when the mixture becomes pasty it is diligently stirred, to facilitate the extrication of carbonic acid and the combustion of carbonaceous matters. Towards the end of the third hour, the temperature is considerably raised, and at the expiration of the fourth, while the mass is hot and soft, it is raked out into large cast-iron trays, and cut by a spade into square cakes, which are piled away for use. These *frit-bricks* are supposed to improve by age, and are sometimes kept for twelve months or more. Where the fritting is omitted, as it now often is, the materials must be thoroughly dried before the founding; for which purpose the sand is first calcined at a dull red heat in the colcar, then carefully sifted: the chalk is also raised to a more moderate heat, for the purpose of expelling moisture, not carbonic acid. The sand and chalk are finely sifted and thoroughly intermixed with the other materials, also in a dry and pulverulent form. The mixture is shovelled into the pots when they are at a white heat. The furnace being at its greatest heat, the first quantity thrown in fuses down in about 8 hours; another portion is then thrown in, and so on until the pot is sufficiently full. Vitrification is usually complete in about 18 hours. When gas ceases to be disengaged, the temperature is gradually lowered, by closing the draught-holes, and the chinks in the doors of the cave are stopped with mortar. In a few hours the glass is perfectly clear: the fire is then raised a little, and the glass-gall being skimmed off, the glass is ready for working. In order to preserve a clean surface, an earthenware ring of the same material as the pots, and about 2 feet in diameter and 3 inches thick, is floated on the melted glass after the surface is skimmed. The surface of the glass is much cleaner within the ring than without.

It is difficult to convey a complete idea in writing of the remarkable series of processes by which a lump of glass is expanded into a large sheet or table. In the Great Exhibition Messrs. Hartley & Co., the eminent crown-glass manufacturers of Sunderland, had a most instructive series of specimens, showing, first, the lump of glass adhering to the blowing tube; then the various shapes which it is made to assume, until it finally becomes a large table. Those persons who studied these specimens, as well as the huge glass-pot (represented in Fig. 1069) and the model of the crown glass furnace, will be the better qualified to follow our description. Indeed, the general intelligence of the public would be promoted, writers on the useful arts assisted, and the cause of education forwarded, if an industrial museum, such as the Great Exhibition, could be made permanent, although on a much smaller scale; nor do we see any good reason why every town should not have its Useful Arts Museum, open to all, with competent persons to give instruction therein. Had such powerful educational means been in existence during the last half century, many a poor inventor would have been spared much useless toil, anxiety, and expense.

Fig. 1069. CROWN GLASS POT.

The man collects on the end of his blowing-tube, from the inside of the ring, as much glass in successive layers as will form a disc or table of about 9 lbs. weight. An experienced workman seldom fails more than an ounce or two in the correct weight. After cooling the blowing-tube which has been heated in the melting furnace, by letting water drop upon it, he rolls this mass of glass, technically called the *piece*, upon the marver, into a pear-shaped lump, *a*, Fig. 1070, while a boy slightly distends it by blowing. It is next held in the mouth of the small blowing-furnace to soften: again rolled on the marver to correct inequalities in the thickness of the sides, and to collect the great mass of glass at the lowest point, thereby elongating the neck, as at *b*. In this marvering the outer extremity of the glass is made conical, and the extreme end is called the *bullion*. In again blowing out the bulb, the man supports it on a horizontal smooth iron rod, called the *bullion-bar*, placed across a stool, or across a pit in front of the marver, and he expands the bulb until it is nearly spherical, as at *c*: to preserve the perfect form of the sphere, the man, while blowing, gives it a continuous motion along the bullion-bar, but the effect of this is to form waved lines round the centre of the table. At Mr. Hartley's works the bullion-bar is dispensed with; the glass is supported by a tube attached to the bullion, and held by a boy while the blower causes the tube to revolve. The boy is protected from the great mass of hot glass by a shield through which the supporting rod passes. The globe is next softened at the blowing-furnace and blown out until quite spherical. It is then conveyed to the bottoming hole, Fig. 1071, which is similar to the flashing-furnace, but has a smaller opening: here it is exposed to the direct action of the flame, the man being screened from the heat by a wall in front and a little on one side of the furnace. The tube is supported on a hook projecting from the wall, and in revolving the globe the part opposite the tube becomes softened by the heat, and yielding to the action of centrifugal force, assumes the form shown at *d*, Fig. 1070. It is then removed, and another man applies a pontil tipped with melted glass to the centre of the flattened part, when the first man detaches the blowing-pipe by touching the neck of the globe with an iron wetted with cold water. The blowing-pipe carries with it a piece of glass, leaving a corresponding hole in the flattened sphere at a point exactly opposite the attachment of the pontil, as shown at *e*, Fig. 1070. By the action of heat and centrifugal force, the flattened sphere becomes more and more flat, while the hole becomes larger and larger, and at length entirely disappears on the glass flying out into a flat table. This final result is approached by gradual steps. The glass is held by the pontil and exposed to a moderate flame before the nose hole: it is rotated with gradually increasing velocity, when the hole caused by the removal of the blowing-pipe enlarges. It is next heated more intensely before the flashing-furnace, and acquires the form shown in Fig. 1072

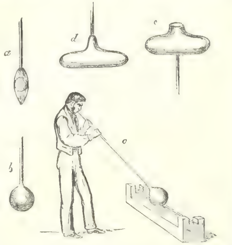

Fig. 1070. PROGRESS OF THE MANUFACTURE OF A TABLE OF CROWN-GLASS.

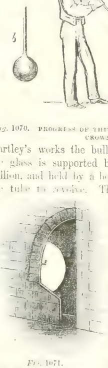

Fig. 1071. THE BOTTOMING-HOLE.

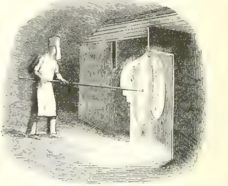

Fig. 1072. THE FLASHING-FURNACE.

By increasing the velocity of rotation, the flattened globe at length flies completely open with a noise something like that produced by quickly opening a wet umbrella: in this way a flat circular disc nearly 60 inches in diameter is produced, of uniform thickness except at the point of attachment to the pontil, where there is a swelling called the *bull's-eye*.[1] A sheet of such dimensions would fold together while in its soft state if the man were to cease to rotate it; he therefore continues the motion until the table is sufficiently cool. It is then placed on a large iron fork, held by an assistant; the pontil is cracked off, and the plate transferred to the annealing arch Fig. 1073, where it is made to rest on edge in two strong parallel iron supports, running the whole length of the annealing kiln. The arch is of sufficient capacity to receive two rows of tables, as shown by the dotted circles: the annealing is continued for 24 hours, during which the whole arch is raised to a uniform heat, and allowed to cool gradually. A shorter time suffices when the arch is strongly heated at one end, and nearly cold at the other, while the tables are slowly moved forward towards the cold end.

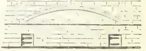

Fig. 1073.

A pot containing half a ton of metal will produce 100 tables. At an ordinary crown-glass house 4 such pots are emptied in three days every week. The glass-gall, and the residue in the pots, are *refined* by being

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(1) The glass at the edge of the disc is also in some cases a little thickened. It is evident that the portion of the glass attached to the end of the blowing-tube afterwards becomes the edge or outer rim of the table: the thickening of this edge is prevented by a *cutter*, attached to the marver, consisting of an iron crescent, into the concave of which the man places the neck of the piece or solid ball of glass, while the boy is distending it by blowing: it is thus prevented from thickening at that point. In subsequently re-heating and blowing, another form of cutter is used. The edge of a bar of wood attached to the marver will even answer the purpose.

poured into cold water. The glass is thereby disintegrated, and, falling into a coarse powder, a portion of the saline impurities is dissolved out: the glass on being drained dry is mixed with fresh raw materials.

SECTION VII.—CYLINDER-GLASS.

On the continent of Europe the above method of making window-glass is not adopted, but instead of it the glass is first formed into a cylinder, closed and rounded at both ends, which are then cut off, and a crack being run down the length, or the cylinder itself attached to a three-pronged pontil, is cut open with shears, as in Fig. 1074. The cylinder is then flatted out in a furnace.[1] The glass for the Exhibition of 1851 was made somewhat in this way. It is coarser in texture, more wavy and dull than crown-glass, but it allows of larger sheets being manufactured; for crown-glass cannot be cut up without considerable waste, in consequence of the circular form and the central bull's-eye. But while the glass manufacture was subject to the regulations of the Excise, it was more profitable for the maker to produce crown-glass tables than cylinder sheets, because the duty was levied on the weight of glass produced, and not on the number of sheets, and it is possible to produce a greater yield from the same weight of crown than of cylinder-glass, in consequence of the smaller thickness of the former, and also not having to cut off any portions, as is the case in the manufacture of the latter.

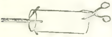

Fig. 1074.

The manufacture of cylinder-glass is of German origin; whence the product is sometimes termed *German plate-glass;* and on the introduction of the process into England it was called *British sheet-glass.* It is also known as *broad window-glass, spread window-glass,* and *inferior window-glass.* This last term arose from the coarseness of the materials used, the alkali being soap-boilers' waste and kelp; but of late years the manufacture has been considerably improved, and it is now inferior to crown-glass in lustre only.

Broad-glass is made without flashing. The raw materials are fritted with considerable agitation for 20 or 30 hours, and the frit is introduced into the glass-pots red-hot from the calcar. It is vitrified and ready for use in 16 or 20 hours. The workman then collects a massive glass ball round the knob of his blowing-pipe, which is pushed forward until a groove is produced at *a*, Fig. 1075. He then rounds the ball on the marver, and slightly distends it by blowing until its form becomes that shown in section, Fig. 1075; and from the thick mass of glass below the air-bubble, the cylinder is distended and lengthened, the glass being first made to assume the width, and then the length of the intended cylinder. The ball of glass having been heated, the man then holds it up, in a vertical position, over his head, and blows into it: the soft glass yields to the distending power, while the heavy bottom, descending by its own weight, forms a sort of flattened bottle, Fig. 1076. The proper width of the intended cylinder being thus attained, the pipe is quickly lowered so as to have the glass below instead of above, and the man keeps swinging it backwards and forwards, blowing into it all the time. The thick bottom retaining its heat much longer than the thin sides, yields to these two forces, and increases in length, until it settles by cooling into a form similar to that of Fig. 1078. If the man were to blow without swinging, the bottle would assume the form indicated by the dotted line.

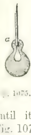

Fig. 1075.

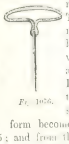

Fig. 1076.

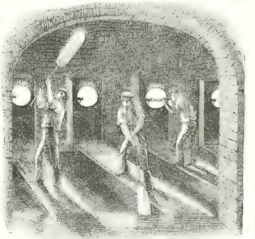

Fig. 1077.—BLOWING AND SWINGING CYLINDER-GLASS.

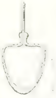

Fig. 1078.

Fig. 1079.

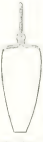

Fig. 1080.

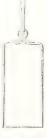

Fig. 1081.

In this way, by repeated heating, swinging, and blowing, the intended length of the cylinder is obtained, and the glass is of the form shown in Fig. 1079: it is conical, and terminated by a hemisphere, of which the middle point *c* is the thinnest part of the whole vessel. The man now blows air into the vessel, and before removing his mouth, closes the aperture of the pipe with his thumb: he then holds the end, Fig. 1079, in the flame until it bursts under the increased elasticity of the enclosed air. The thick and uneven margin of the aperture is trimmed with scissors, and

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(1) Although this method of making sheet-glass is not so well known as that described in the preceding section, it is at least as ancient. In the *Diversarum Artium Schedula*, which has been referred to the 13th century, a complete description is given of the mode of manufacturing cylinder-glass.

enlarged with the pucellas to the proper diameter, as in Fig. 1080. The other parts are also straightened, and brought to a uniform diameter, as in Fig. 1081. In long and wide cylinders, the lower part is apt to become too thin, and requires extra glass to be incorporated with it before the cylinder is opened. The neck or cap is then removed, by supporting the cylinder on a wooden rod and turning the upper part two or three times in the curve of a bent iron heated to redness, as shown in Fig. 1082: a drop of water allowed to fall on the heated line produces fracture and separation of the cap. By a similar process a crack is made down the length of the cylinder, and it is now in the form shown in Fig. 1083, ready for the operation of spreading or *flatting* into a sheet of glass. This is performed in a furnace, the principal parts of which are shown in perspective, Fig. 1084. In the arched space A, *a* is the ash-pit and *r* the grate; *b* the ash-pit door, and *d* the stoke-hole. The flame enters the upper part of the furnace through the openings *c c*, first plays on C, which is called the *flatting-hearth*, then passes into B, the annealing or cooling-furnace, and escapes by the flue or channel D, by which the cylinders are introduced. C and B are connected by means of a low-arched wide aperture, E, to allow the passage of the plates, and also by a smaller higher opening *g* for the admission of flame. The heat is regulated by opening or closing the apertures *c c*. The flattener stands in front of the aperture *l*; the man at the cooling-furnace before *m*, and an assistant pushes the cylinders forward along a railway into D. The *spreading-plate* or *flatting-stone* must be perfectly even, free from roughnesses or inequalities, as the soft glass of course moulds itself to the surface upon which it is flattened by heat. This plate is made of fire-proof clay mixed with cement, and ground smooth; or it is made of a thick plate of devitrified glass: in this country, the sandstone of Godstone in Surrey has been found to answer the purpose. The fact is, however, that the choice of a proper flatting-stone constitutes one of the chief difficulties of this elegant and remarkable branch of the glass-manufacture.

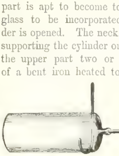

Fig. 1082.

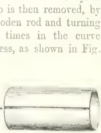

Fig. 1083.

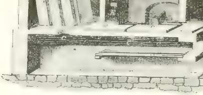

Fig. 1084.—Flatting Furnace.

The operation of spreading is begun by introducing the cylinders into the long flue leading into D, and as they are pushed forward they gradually soften. A man standing before the aperture *l* takes up one of the cylinders with an iron tool, bent at a right angle, and places it on the flatting-stone with the cracked side uppermost: the cylinder soon opens, and he makes it straight and even with a rod of iron furnished with a wooden polisher, Fig. 1085, dipped in water before being used. All the curves and lumps being thus removed, the sheet is pushed into the annealing oven, where it cools down. Another man then places it on edge in an inclined position, and when 30 or 40 sheets are thus collected, an iron rod *s*, Fig. 1084, is inserted; and the processes are conducted in this way until the annealing-furnace is filled.

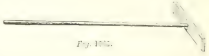

Fig. 1085.

Such is the German method, which has long been practised on the Continent. In 1842, Messrs. Chance of Birmingham introduced it into England, with certain improvements, which they patented. Instead of at once removing the glass from the flatting to the annealing-furnace, and lifting it to the cooling-bed while soft and liable to distortion, they flat and cool it by passing it through a succession of decreasing temperatures, so that it is not lifted until it becomes quite stiff and rigid. By this arrangement the workman can flatten while the annealing is going on, which could not be done in the old process, because the temperature of the flatting kiln must be reduced with that of the annealing kiln to which it is contiguous, thus leading to the successive heating and cooling of the kiln, and waste both of time and fuel. At Messrs. Chance's establishment the flatting and annealing kilns are two circular buildings communicating with each other, each consisting of an exterior wall A, Fig. 1086, and interior masonry work B, the intervening space being a circular arched vault. In each vault is a cast-iron frame F, moving on casters, and capable of being turned round by a winch on the outside. The frame in the flatting-kiln carries the flatting-stones and *lagres* L, 8 in number, and in the annealing-kiln a number of metallic wires D, radiating towards the centre of the building, for supporting the sheets of glass. The flattening-kiln is heated by the grate G, and in order that the stones and lagres, which will have cooled during the rotation, may be re-heated and arrive at the position E at a proper temperature, a second smaller grate is placed at H. If coke be used, a chimney at C will be required, but with wood fuel it will not be needed. Partitions P are placed at certain intervals, to prevent the too rapid dissipation of the heat from those parts where it is most required, and to retard the entrance of cold air through the openings in the external wall. At the bottom of the partitions are spaces to allow the frame with the stones and glass or the wires and glass to pass below. The space I is reserved for re-heating the wires. The space J, on which the glass is shifted from the lagres to the wires, is lighted by gas. The kiln is worked in the following manner.—The cylinder of glass is first placed in the position K; then in that of L; thirdly it is introduced through the external wall and placed on a stone M, suspended over the lagres: it is lastly placed in the position N on the lagre beneath. To prevent the cylinder rolling off, the stones have a ledge *l*. This part of the kiln, 3——3, Fig. 1086, is shown separately in Fig. 1087. The frame F is then turned round till the cylinder of glass occupies the position O opposite the working hole *o*, through which it is then flattened in the ordinary way. From O the glass passes to G, and thence successively to R: thence it is shifted to the position T on the wires, by the flattener using his instrument through the opening S; and after passing through the successive positions arrives finally at V, where it is drawn at W fully annealed. Thus each sheet of glass after having been flattened remains on the stone during the time that other cylinders are being flattened, and before the sheet is lifted off the stone, it has passed through a gradually decreasing temperature, and has become rigid. The annealing is also carried on without lowering the temperature of the kilns by the movement of the frame, and the sheets being isolated by the wires, become more quickly annealed.[1]

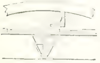

Fig. 1087.

Mr. Hartley of Sunderland is also an improver on the German method. In his process the operation of flatting does not occupy more than a minute; the flatting-stone is made to revolve in such a way that the cylinder upon it is gradually exposed on all sides to the action of the fire, and thus one side of the cylinder is not hotter than the other. It is difficult to obtain perfectly flat glass for polishing, on account of the film of air between the flatting-stone and the cylinder. Mr. Hartley overcame this difficulty by perforating the flattening-stone with holes [illegible] inch in diameter, and about 1 inch apart.

In Mr. Farthing's arrangement, the kiln is heated by flues under the floor, around the walls, and over the arch, thus protecting the glass from dust or hard particles from the fuel, and allowing cheap fuel to be used.

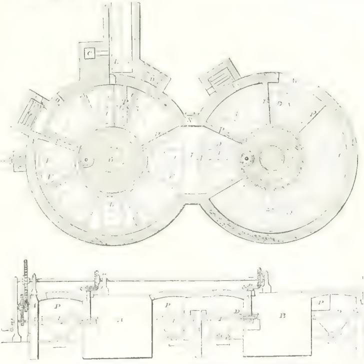

Fig. 1086. PLAN AND ELEVATION (IN SECTION) OF MESSRS. CHANCE'S FLATTING AND ANNEALING KILNS.

SECTION VIII.—PLATE-GLASS.

This beautiful variety of glass is similar to crown-glass, the only essential bases with silicic acid being soda and lime; but a larger proportion of alkali being used, the point of fusion is lower than in crown-glass. Plate-glass requires to be as transparent and colourless as possible, in order that, when used for mirrors, the light may be reflected from the amalgam at the back; these qualities can only be ensured by purity in the materials. A good mirror should also reflect an image in its true and natural form, without distortion of any kind; hence there must be no waves or lumps in the glass to produce irregularity of reflection. The difficulties of producing faultless plate-glass are almost as great as in the case of optical-glass; and as the working arrangements are of a very costly description, the manufacture is in this country in the hands of a few powerful companies. It cannot, however, be said that they have attained perfection in the art. At the Exhibition of 1851, plates of enormous dimensions were exhibited, but in quality they were not equal to the French. A writer in Newton's *London Journal*, Vol. XXXIX, offers an ingenious explanation of the cause

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(1) In the above description we have retained the present tense, in which the article was originally written; but in revising it for a new edition, we must remind the reader that in a large, well-directed factory, processes are being frequently modified or superseded. For the changes that have come over this one, we refer to the APPENDIX.

of our inferiority in this respect, by referring to the fact, that many neutral salts combine together by fusion in atomic proportions, and form new and definite compounds: thus, carbonate of potash and carbonate of soda, when mixed atom for atom, unite, and produce a compound more easy of fusion than the more fusible of the two; so also fluor spar and sulphate of lime, two remarkably infusible substances, melt readily, when mixed at a low red heat, into a mobile transparent fluid: so also with respect to the silicates: a mixture of silicate of potash and silicate of soda will, if in atomic ratios, fuse much more readily than either of them alone; but if one of them be in excess, (the silicate of soda, for example,) then the silicate of potash would unite with exactly sufficient of the silicate of soda to produce a glass of comparatively easy fusibility; while the less easily fusible silicate of soda in excess, would form a kind of network throughout the mass. This less fusible glass thus entangled in the more fusible, and of different density therefrom, would form striæ, and produce unequal refraction and distortion of figure. The excellence of the plate-glass of St. Gobain is said to be due to the fact that it is a true chemical compound, consisting of one atom of the trisilicate of soda and one atom of the trisilicate of lime, with a small percentage of alumina. The English plate-glass, on the contrary, consists of a mixture of two glasses of different densities. On placing a specimen of French and English plate side by side, and viewing some distant object in each by reflection, the French glass will give a clear, sharp outline, while the English will reflect two or more images in a hazy and imperfect manner. It must, however, be remembered that the French are particularly careful to ensure the purity of their materials, that they manufacture the most costly description of plate-glass, and that the specimens at the Great Exhibition were *picked* from a very large stock. Our manufacturers, on the contrary, work for the million, a very large portion of their supply being for glazing shop-windows and the windows of private houses, as well as for cheap looking-glasses; whereas, the French never glaze with plate-glass, and their choicest productions being costly, the demand for them is limited. It is of far more importance that the masses of the people should be supplied with such an article of comfort and luxury as plate-glass, even though it be of a somewhat inferior description, than that the manufacture of the superior article should be so costly as to place it within the reach of the wealthy only. The French plate-glass is unquestionably good; but it is doubtful whether it could be applied to the purposes of glazing, as it would be likely to suffer from the action of the weather. The Editor has been informed by a plate-glass manufacturer, that if the materials be combined in the melting-pot in true atomic proportions, the portion of the alkali volatilized by the heat will disturb the atomic arrangement; and that if an excess of alkali be added to compensate for this loss, then the glass becomes *basic* or alkaline, and, attracting moisture from the atmosphere, soon loses its polish and decays. In plate electrical-machines a dry glass is of importance; and hence crown-glass, although inferior in colour, is to be preferred. The effect of the Exhibition of 1851 was to give a healthy stimulus to our plate-glass manufacturers; for we read in the Jury Report of 1862 of the "superior quality" of the plate-glass "which both the British and foreign departments continue to produce." It is also added: "This is a manufacture almost perfected."

In this country the best quality of soda ash is employed. At St. Gobain pure carbonate of soda is obtained by decomposing sulphate of soda with lime and charcoal. Potash is not used for plate-glass, except a small portion of nitre to destroy carbonaceous matters. Glass made with soda and lime flows more freely than that made with potash and lime at the same temperature, and is hence better suited for casting. The glass-gall of the soda glass, consisting of sulphate of soda and chloride of sodium, is also more volatile than potash gall, and is hence more readily got rid of from the open pots in which the glass is fused. The lime may be introduced in the form of chalk, quicklime, or dry slaked lime. The sand and alkali must be well purified from oxide of iron, and all the materials, with the exception of the cullet or broken plate, must be in powder, sifted and ground if necessary. In England, arsenic is used, and in France, borax: the latter material greatly improves the colour, but is said to produce a soft glass.

In the manufacture of plate-glass, the materials are not fritted, as was formerly the case, but are sufficiently pure to be placed in the pot in 3 successive charges: they are melted in open pots, and by the side of them are other crucibles or *cisterns*, Fig. 1088, called *cuvettes* in France, where they are quadrangular in form, into which the glass is ladled when ready for casting. The English pots and cisterns are of the same form as those used in the manufacture of crown-glass. At the Thames Plate-glass Works, the melting-pots are 50 inches deep, and 48 inches across at the brim, and are capable of holding from 28 to 30 cwt. of glass. The cisterns hold from 3 to 6 cwt., and have an indented ring about one-third of the way up from the bottom, into which the limbs of the huge tongs fit, at the casting. Vitrification is complete in about 20 hours, and when properly refined, a copper ladle, 10 or 12 inches in diameter, fixed to an iron handle 7 feet long, is plunged into the glass-pot, and raised full of melted glass; the ladle being supported by an iron rest held by two men, its contents are conveyed to another furnace, and poured into the cistern, which is filled in this way and left for 12 hours to fine, samples being withdrawn from time to time for examination. During the first 6 hours the founding goes on, and in the second, the fining; during which the temperature is lowered to the proper point for casting.

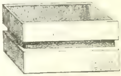
Fig. 1088.

The casting is performed on massive tables of metal, which at the Thames Plate glass Works are of iron, 20 feet long, 11 broad, and 7 inches thick, made perfectly smooth and level. Brass or bronze was formerly used; the bronze slab at St. Gobain weighs 50,000lbs., and cost 1,000*l*. But the liability of this metal to crack first led the British Plate Company to make trial of iron, which was found to be quite successful; and at St. Gobain they have abandoned the use of bronze for the more common metal. The foundry at Ravenhead is described as a fine room 339 feet long, 155 feet wide, and lofty in proportion. The melting furnaces, which are ranged down the centre, occupy about one-third of the whole area of this apartment. The annealing ovens A F, Fig. 1089, are placed in two rows, one on each side of the foundry, and occupy the greatest proportion of the side walls. Each oven is 16 feet wide and 40 feet deep. Their floors being level with the surface of the casting table T, the plates are deposited in them as soon as they are cast.

When the melted glass in the cistern is in the proper state for flowing readily and equably, the cistern is taken out of the furnace by means of tongs fitting in the groove, shown in Fig. 1088. It is then raised by a crane, placed upon a low carriage, and removed to the casting-table. The outside of the cistern is carefully cleaned, and the glass skimmed with a broad copper sabre, to prevent any impurities from mixing with the glass on the casting-table. The cistern is then wound up to a sufficient height by means of a crane, and swung over the upper end of the casting-table, which has been heated by hot coals spread over it, and then wiped perfectly clean. The cistern being tilted over, a torrent of melted glass is suddenly poured out on the surface of the table: it is prevented from running off the sides by ribs of metal, *cc*, one of which is placed along the whole length of each side, their depth being the exact measure which is to be given to the thickness of the glass. When the cistern has been emptied, a massive copper cylinder, R, 3 feet in diameter, extending entirely across the table, and resting on the side-ribs, is set in motion, and spreads the glass out into a sheet of uniform breadth and thickness. The pouring out of the glass is a grand sight, and the variety of colours exhibited by the plate immediately after the roller has passed over it is beautiful to behold. In order to remove all impurity from the casting-slab, a washer *w* is drawn immediately in front of the fluid glass; the excess of glass pours over the front edge into a trough filled with water: the roller then passes off the slab, and is received in the grooves *n n*. The casting is then cleared of any redundancy at the sides; a thick flange of the still soft glass is turned up at the end at *l*; and when this flange has become somewhat rigid, a rake-shaped iron is applied to it, and the plate is forced forward into the annealing-oven, or thrust upon a wooden platform moving on wheels and so conveyed to the oven, where it remains about five days, in a horizontal position, exposed to a gradually diminishing temperature.[1]

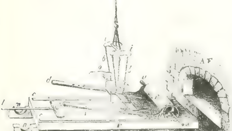

Fig. 1089. THE CASTING TABLE.

Grinding and polishing. The plate being still hot and yielding when it is slid into the oven, takes an impression of the bricks of the oven upon which it rests, while the upper surface is generally made smooth and bright from the action of the fire, but it is not flat. The plates as they come out of the annealing-furnace are about ½ inch thick, of an irregular mottled appearance. They are carefully examined, to see whether the glass is sufficiently free from defects to admit of forming large plates, which, of course, have a much greater comparative value than small ones. If the defects are such as cannot be removed by grinding, the plate must be cut up into smaller plates, so that the defective portions may be rejected. The plates having been squared, next undergo the processes of grinding and polishing. These were formerly done by hand, but of late years this laborious work is almost entirely performed by machinery. The first object is to produce a level surface, which is done by grinding one plate upon another, a rough or rolled surface being opposed to the comparatively smooth or casting-plate surface. The grinding machines for large plates are arranged in pairs consisting of two benches of stone, 15 feet long, 8 feet wide, and 18 inches high. On the surface of each bench one or more plates of glass are imbedded in plaster-of-Paris, close together, and quite level. Other plates of glass are cemented upon the lower faces of two swing tables or runners, which are made to traverse over the fixed beds by appropriate machinery, in such a way that each runner is made to rotate around its own axis, and by a combination of two movements to change continually the relative position of the fixed bench and runner. Such an arrangement tends to the mutual correction of the two surfaces of the glass, and greatly assists the equal distribution of the sand and water. All the irregularities of the surface are first ground out with sharp river-sand, which has been washed and sifted into three sizes: the sand and water are thrown on by hand from time to time. When the plates have been ground quite flat, the finer sand is employed: this is followed by one finer still, which removes the scratches made by the coarser. The plates of glass are well washed between every change of sand, and when one side has been ground, the plates are reversed and the other sides ground.

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[1] It has been proposed to form plate-glass by stamping, instead of rolling, between two metallic plates. Small plates are fluted or chequered on their surface by means of a steam-hammer, hydraulic press, or rollers arranged between two furnaces, one of which is similar to the flatting-furnace; the other is the annealing furnace.

When the plates become sufficiently smooth to require the application of emery, there is a tendency to cohesion between the surfaces, which, travelling over each other with moderate velocity, produce so much friction that one surface will frequently tear the glass from the other. Hence it has not been thought safe to trust the next process, namely, the *smoothing*, to machinery, and hand labour has been employed. Lately, however, machinery invented by Mr. Blake, of the Thames Plate-glass Works, has been introduced. The Editor has seen it in action, and it appears to answer the purpose admirably; its object being to imitate the motions of the arms and legs of the persons employed in smoothing. The following is the method by hand. The plates are put upon flat stone benches about 2 feet high, covered with wet canvas, which serves to hold them firmly. The surface of each plate is sprinkled with emery and water, and a small plate is usually used as a grinder or runner; but if the plates be large, a few flat lead weights, of about 14 lbs. each, are put on the runner near the middle, to distribute the pressure uniformly, and the runner is made to traverse with a swinging rotatory stroke: each stroke is made to follow a slightly different path from the preceding one, and the runner is gradually twisted round as the smoothing proceeds. In this way every part of the bed-plate and runner is exposed to an equal amount of grinding, and the emery is uniformly distributed. Young girls are employed on small plates; but the large ones, which require more dexterity, and a much larger amount of traverse, are smoothed by two women, who stand on opposite sides of the bench, and, placing their outstretched hands flat upon the runner, swing it with a kind of eccentric circular stroke. Women are said to perform this rude work better than men, on account of their superior delicacy of touch, which leads them to use the moderate degree of force required, and to detect and remove particles of grit amongst the emery. About three sizes of carefully washed emery are used; and between every size the plates, canvas, bench, and hands are thoroughly washed: the dress must also be quite clean, as any particle of grit would ruin the work, and require the smoothing to be recommenced. The fine emery last used gives a very smooth and partly polished surface.

The polishing is completed by rubbers, covered with thick felt, and worked by machinery. The plates of glass are embedded close together with their surfaces quite level upon movable platforms fixed upon a traversing bed. The rubbers, which measure 8 by 6 inches each, are attached, 1 foot asunder, to reciprocating carriages, which drag the rubbers backwards and forwards over the surface of the glass, while the latter traverses beneath the rubbers a space equal to the distance between the two lines of rubbers, so as to expose all parts of the glass equally to their action. Each rubber is made to exert a pressure of about 15 lbs., by means of lead weights. The powder used for polishing is Venetian pink: this contains only a small portion of oxide of iron, mixed with earthy matter: it admits of being mixed with water, and thus reduces the friction, and prevents the glass becoming heated by the action of the rubbers. Tripoli, crocus, or putty-powder, used with water, are too active to produce a high polish on glass; but they may be employed dry for the last finish in hand-polishing. In polishing by machinery, dry powders must be avoided on account of the friction and heat evolved. Hand-polishing is very tedious, and is apt to produce a wavy appearance; hence machine-polished glass is to be preferred.[1] The machinery represented in Figs. 1090 to 1093 will convey a very good idea of that used in the grinding and polishing of ordinary plate-glass.

The grinding and polishing of the plates reduces their thickness as much as one-third, and in some cases one-half. Should the glass be defective, the polishing will only serve to heighten the defects; hence, a second and more careful examination and selection of the plates is now made. The defective ones are cut up into smaller plates, and these are polished again: the perfect ones are reserved for silvering, the process for which will be described presently.

To prevent or diminish the waste in the grinding, Mr. Bessemer has proposed to alter the whole of the arrangements of this manufacture. The furnace and the pots of glass are so arranged, that each pot, as soon as its contents are in a fit condition, is wheeled out of the furnace, and tilted, so as to pour the melted glass between two rollers placed at a certain distance apart, and kept cool by a current of water passing through them. In this way a uniform thickness of glass is ensured. The hot sheet of glass, on passing between these *forming* rollers, is received between two *finishing* rollers, and being closer together, and moving with accelerated speed, the glass is made smooth and flat. A fluted or a chequered surface can be given to the glass by the making rollers: such a surface is said to retain the sand used in grinding, and greatly to facilitate that operation. After the hot plate has passed between the second pair of rollers, it slides down a curved surface upon a flat table, and when sufficiently rigid by cooling, it is transferred to the annealing-kiln, which is heated by hot air, the direct action of the fuel being prevented. In polishing, the plate is secured to a slab of slate, and an endless band or strap of gutta percha, covered with felt and polishing material, is made to pass rapidly over the surface of the glass, in contact therewith: at the same time, the band is made to traverse slowly at right angles to the line of its motion.

Plate-glass is sometimes made by the blowing and flattening process already described. The irregularities of its surface arising from the imperfect action of the flattening process are, for the best glass, removed

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(1) In Knapp's Technology, translated by Drs Ronalds and Richardson, is an excellent article on Glass, in which the various modes of manufacture, as practised on the continent of Europe, are given. The translators have added a variety of details not to be found in the original, among which may be mentioned Messrs. Chance's and Messrs. Nicholson and Wadsworth's improvements in the manufacture of plate glass. We must also refer to the admirable chapter on glass in the second volume of Dumas's "Chimie appliquée, &c." and to Gmelin's valuable notice in the third volume of his "Handbook of Chemistry."

by grinding and polishing. The moving parts of the grinding-machine employed for the purpose will be understood from Fig. 1090, in which the dotted lines represent the framing. This consists of continuous beams 1, 1, united by vertical parts 2, 2; and above is an axis 3, 3, carrying one pair of bevel-wheels, which turn the upright shaft 4 and its crank 5 to the right or left at pleasure. The pin of the crank 5 communicates a circular motion to that part of the moving-table to which it is attached, while the fixed radius bar 6, 7, 8 makes the centre of the table describe an arc about the point 6, and these two motions bring all parts of the running surface, in succession, in opposition to nearly every part of the lower bed: this bed rests on railway bars 9, 9, and is very slowly reciprocated to and fro by the bar 10, which sets a large number of machines in motion by means of a crank attached to it. The circle described by the crank 5 is about two-thirds of the length of the moving-table. The lower face of this table is covered with slate, upon which the glass is cemented: another sheet of glass is cemented upon the lower table, and the upper table is loaded with 4 or 8 weights, arranged so as to distribute the weight equally. Coarse emery and water are used for the grinding; and when the machines are used with finer emeries for smoothing, the whole apparatus is carefully washed. In some factories the plates of glass are smoothed by rubbing them upon one another by hand.

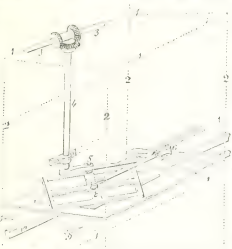

Fig. 1090. PRINCIPAL PARTS OF GRINDING MACHINE.

The sheet-glass having been ground flat and smoothed, is polished by machinery, the principle of which is roughly illustrated by the following figures. 1, 1, Figs. 1091, 1093, is the main shaft, extending throughout the length of the building, and having for every row of machines one double and two single cranks, which, by means of connecting-rods, move the two long central beams 2, 2 to the right, and at the same time the two exterior beams 2′, 2′ to the left. The travelling beams, or rods, carry rubbers 3, 3, about 12 by 5 inches on the face, and covered with leather; they are suspended by a joint to the loaded levers 4, 4′, Fig. 1092, which press them on the glass.

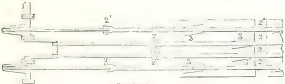

Fig. 1091.

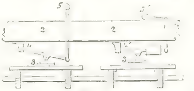

Fig. 1092.

The joint which unites 4 and 5 is situated in a mortice of the long travelling beam 2. In order to raise the cushion from the glass and throw it out of work, the piece 5 is raised and laid down in the position 5′, which brings the lever 4 into the position 4′. The rubbers all assume an inclined position in consequence of the several tables which carry the glass having a very slow transverse motion, which is brought about in the following manner:—The main shaft 1, 1, communicates with a pair of sliding bevel-wheels 6, 6, Fig. 1093; these through 7 move the tangent screw 8, and thence the worm-wheel 9, which latter, by the pair of bevel-wheels 10, 11, moves the long shaft carrying the line of pinions 12, 12, one or two of which are under every table, and traverse the same by the aid of plain rollers 13, 13. A tumbling-bob is affixed to the table nearest the cranks and gear, by which the position of the pair of bevels 6, 6, is shifted to make the tables traverse first in the one and then in the opposite direction.

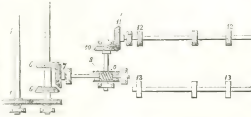

Fig. 1093.

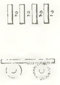

Fig. 1094.

Silvering.—A leaf of tin foil of larger dimensions than the plate to be silvered is spread out upon the silvering table, and mercury brushed over it. When the surface is uniformly covered, more quicksilver is added, so as to attain a height of 2 or 3 lines; the coating of oxide is removed with a wooden rod, and a brilliant surface produced. The plate of glass is pushed slowly forward from the side, with the longest edge foremost, and dipping below the surface of the mercury so as completely to exclude the air.

In this way the glass is brought into contact with the metal, and a brilliant surface produced. The plate may now be said to be floating on a bed of mercury. To get rid of the excess of metal the mirror is loaded with weights, and the table inclined 10° or 12°, when the mercury flows away. A further portion is got rid of by setting the plate up on edge, and in the course of 3 or 4 weeks a dry permanent coating of tin amalgam is left on the glass.

This method has many objections: the vapour of mercury is poisonous to the workman; the plates are liable to fracture from the heavy load placed upon them; and when set up on edge, drops of mercury sometimes trickle down, carrying the amalgam with them, thus rendering it necessary to re-silver the whole mirror. Moreover, the amalgam is liable to spoil by crystallization or carriage. Mr. Drayton's method is free from these defects. His *silvering fluid* is obtained by mixing ammonia with nitrate of silver, filtering the mixture, and adding to it an alcoholic solution of oil of cassia: (1 oz. nitrate of silver, 3 oz of alcohol of 87 per cent., and 20 to 30 drops of oil of cassia, may be employed.) This fluid will, on the addition of a *reducing liquid* consisting of 1 part oil of cloves in 3 parts alcohol, deposit bright metallic silver. The glass to be silvered is made perfectly clean, and is surrounded by a rim of putty: a layer of silvering fluid, to the depth of 1 or 2 lines, is then poured upon it. The addition of the oil of cloves solution causes a film of brilliant metallic silver to attach itself firmly to the surface of the glass. The reduction should be slow; for which purpose a very small proportion of the reducing liquid is used; from 6 to 12 drops are sufficient to precipitate 4½ ounces of the solution of silver, and the film of metal is so thin that a square foot of it weighs only from 12 to 18 grains. The action of the volatile oil is to deoxidize the oxide of silver; while the nitric acid, set free, combines with the ammonia.

It is not easy to obtain by this process a perfectly clear unspotted surface. The dark colour of the coating, giving a certain black effect to the mirror, is also a disadvantage. This black appearance is due to the perfection of the silver coating, and the precision with which it reflects the rays of light, so that very few rays reach the eye unless the incident angle be very small, as when a person is standing opposite, or nearly opposite, the mirror. Whereas, the ordinary coating of tin amalgam is crystalline in its character; and although the surface in contact with the glass may appear to be homogeneous in character, yet every square inch of it is really composed of a multitude of crystals, which scatter the light, and reflect it to the eye in almost any position in which the observer may happen to be. It has been proposed by Vohl[1] to form the silver coating for small surfaces, the interior of glass balls, &c., by dissolving gun-cotton, or the explosive substance from sugar, mannite, &c., in caustic potash, by the aid of heat; to add to the brown solution a few drops of nitrate of silver, and then ammonia, until the precipitated oxide of silver is redissolved: it is then to be heated in a water-bath, when, at a certain point of the process, the mixture assumes a blackish brown colour, froths up, and all the silver becomes deposited upon the surface in the form of a mirror, which is said to be more brilliant than that produced by means of ethereal oils.

Mr. Drayton also employed a mixture prepared from 1 part solution of ammonia, 2 parts nitrate of silver, 3 parts water, and 3 of alcohol: this solution was filtered, and mixed with ⅛th part of grape sugar dissolved in weak spirit. [See APPENDIX.]

A few years ago Dr. Faraday gave a lecture on this subject at the Royal Institution. The following was one of the illustrations. Two large plates of glass were mounted in a frame about an inch apart, the bottom and ends being closed with strips of glass, thus forming a long, narrow, transparent box. Before the lecture this was filled with silvering fluid, so that persons on the seats near the lecture-table could see persons on the opposite seats through the silvering fluid. On pouring some of the reducing liquid into the box, the glass sides became silvered, so that those persons who looked at each other through the fluid now saw their own faces reflected.

SECTION IX.—COLOURED GLASS.

All the varieties of glass, and most saline bodies of a vitreous character, such as borax, admit of being coloured by metallic oxides. Most of the colouring oxides afford more brilliant tints with clear white glass made of potash and lime than with those containing oxide of lead: in a few cases, however, lead-glass is to be preferred. The colouring metals are not always added to the glass in the form of oxides: silver is sometimes used in the form of chloride, or even in the metallic state; the colouring metals, however, in the glass are in the state of oxide, in combination with silicic acid.

The art of colouring glass is of early date; indeed, it seems to have been far more easy for the early nations to produce coloured glass than the pure white glass of modern times. The beads found in Egyptian mummies are specimens of true glass coloured by metallic oxides.

The colouring oxide must be intimately mixed with the glass, and both be completely fused. Glass vessels and panes for windows are often coloured merely on the surface, the body consisting of ordinary colourless glass. In forming this, the glass-blower collects the proper quantity of colourless glass on the end of his blowing iron, rolls it upon the marver, and when sufficiently set, dips it for a moment into a pot of melted coloured-glass, and blows out the two together into a cylinder or globe, which is flatted or flashed out in the ordinary manner. Vessels of flint-glass are coloured on the outside in a similar manner, and colourless facets produced by cutting through the layer of coloured glass into the substratum of colourless glass.

In stained and painted glass the metallic oxide is mixed with vitreous bodies capable of easy fusion,

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(1) Liebig and Kopp's "Annual Report of the Progress of Chemistry," vol. iii 1849.

and with fluid vehicles, such as oil of turpentine. These are applied to the surface of the pane with brushes, as in ordinary landscape or figure painting; but the difficulties of the artist on glass are of a much more formidable character than those of the artist on canvas: he must be as good an artist as the latter, but he must also have the faculty of seeing his effects as they will appear after the firing, and not as he lays them on; for the colouring oxides which he employs, especially when mixed up in their fluid vehicles, are dark, dirty, and disagreeable in colour, and have nothing in common with the bright and beautiful effects which we admire in a stained glass window. Where the same figure or pattern is to be repeated many times, it is in some cases printed on the glass with a gentle pressure from an engraved metallic plate, or wooden block, boiled oil being used as the vehicle for the colouring oxide. The pane, having been prepared either by painting or printing, is exposed in an oven or muffle to a temperature sufficient to fuse the vitreous flux and dissolve the colouring material. The glass selected for the purpose of the stainer should be clear and colourless, in order to bring out the colours well; and difficult of fusion, so that the flux and metallic oxide may form a coloured glass upon its surface before it shows any tendency itself to fuse. A glass containing a small proportion of alkali, such as crown-glass, is fit for the purpose.

At the meeting of the British Association at Birmingham, in September, 1849, M. Bontemps brought forward some important practical points connected with the coloured ornamentation of glass and porcelain. In the first place, it was shown that all the colours of the prismatic spectrum may be imparted to glass by means of oxide of iron, in varying proportions, and by the agency of different degrees of heat; the conclusion being that all the colours are produced in their natural disposition in proportion to the increase of temperature. Similar phenomena were observed with the oxide of manganese. If glass coloured with this oxide remain too long in the melting pot or the annealing-kiln, the *purple* tint turns first to a light *brownish red*, then to *yellow*, and afterwards to *green*. White glass in which a small proportion of manganese has been used is liable to become light yellow by exposure to the solar rays, and in certain kinds of window-glass it turns pink or purple by a similar exposure. Such changes also take place in the annealing-oven. In these cases, M. Bontemps supposes light to be the active agent, and not a change in the oxidation of the metal. A series of chromatic changes of a similar character were observed with the oxides of copper; the colours being in like manner regulated by the heat to which the glass was exposed. It was found that silver, although with less intensity, exhibited the same phenomena; and gold, although usually employed for the purpose of imparting varieties of red, was found, by various degrees of heating at a high temperature, and recasting several times, to give a great many tints, varying from *blue* to *pink*, *red*, *opaque yellow*, and *green*. Charcoal in excess in a mixture of silico-alkaline glass, gives a yellow colour, which is not so bright as the yellow from silver, and this yellow colour may be turned to a dark red by a second fire. M. Bontemps is disposed to refer these chromatic changes to variations in molecular arrangement, rather than in chemical composition.

This important series of observations cannot be said to be altogether new. Somewhat analogous effects have long been known to belong to gold and copper. For example:—Gold produces a beautiful red glass. After fusion this glass is colourless; but when heated not above a red-heat, it becomes of a bright red colour. According to Rose, the gold is in a state of protoxide, which forms a colourless silicate by fusion, but when re-heated a little below the temperature necessary to form it, some portion of the protoxide is set free. This protoxide, disseminated in small quantity in a state of extreme division, is supposed to give the red colour. When too much heated, the red becomes brown, which may be due to a partial reduction of the oxide, metallic gold being set free. A similar effect occurs in glass coloured by copper. A glass containing protoxide of copper is colourless after fusion, but it becomes green after heating, owing to the oxide set free. Auriferous glass may be formed from 16 lbs. of quartz, 12 of borax, 12 of nitre, 1 of minium, and 1 of arsenious acid: these are moistened with a solution of 8 ducats of gold in aqua regia, and then fused.

Glass, porcelain, and earthenware are ornamented by a process similar to the above, by covering the vessel or plate to be coloured with a thin layer of some adhesive matter, as essence of lavender, and carefully dusting on this a finely-powdered mixture of the colouring oxide with the proper flux. The colour is then fixed by firing. To obtain a coloured design the surface of the glass may be printed with adhesive varnish from an engraved block, the oxide and flux are then dusted on, and the powder which does not adhere to the varnish is blown off with a pair of bellows previous to firing; or the glass may be entirely covered with varnish, and the powder be sprinkled upon it through a perforated screen or open fabric, such as lace, applied to the surface.[1]

The varieties of coloured ornamental glass are very numerous, and many of them are derived from the Venetians. The *Venetian ball* consists of a number of pieces of filigree glass packed into a pocket of transparent colourless glass, which is adhesively collapsed upon the interior mass by sucking up, thus allowing the outward pressure of the atmosphere to act upon it. The *Venetian filigree* consists of plain and coloured enamel. Canes or sticks of glass are arranged round the interior of a mould: a solid ball of transparent flint-glass is then put in, and when the canes have adhered to it, the ball is re-heated, marvered, covered with a gathering

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(1) The reader interested in this part of the subject is referred to two small treatises contained in Weale's Rudimentary Series, entitled, "An Essay on the Art of Painting on Glass, from the German of Emanuel Otto Fromberg," and "Treatise on the Art of Painting on Glass, or Glass staining, comprising directions for preparing the pigments and fluxes, for laying them upon the glass, and for firing or burning in the colours. From the German of Dr. M. A. Gessert." The latter work contains an Appendix on the Art of Enamelling

of white glass, and the whole is then worked into a vessel. Spiral stems for wine-glasses, &c., are sometimes made in a similar way. *Millefiore glass* (the manufacture of which was a few years ago revived by M. Bontemps) is formed by fusing together a number of tubes of various colours, sections representing stars, flowers, &c.: slices of these tubes are embedded in white transparent glass, the whole forming a pleasing ornament which may be used as a letter-weight. Many of the patterns are, however, very tasteless. *Mosaic glass* is produced by small rods of variously coloured opaque or transparent glass of uniform lengths, ranged so that the ends may form patterns. The whole being properly secured, slices are cut at right angles to the length, whereby the pattern is multiplied. *Schmelz glass* is formed by fusing lengths of coloured glass into each other, so that the section shall resemble carnelian and the agates. *Vitro di trina* is a sort of lace-work, formed by intersecting lines of white enamel or transparent glass, the centre of each mesh being occupied by a bubble of air. *Frosted glass* is formed by plunging the vessel after it has been blown, and while still hot, into cold water; re-heating and re-blowing it; when it appears to be covered with fractures, although it is quite sound and sonorous. The art of making this glass was kept secret by the Venetians, but was re-discovered by Mr. Pellatt.

Aventurine Glass is a glass of a brownish colour interspersed with small spangles which give it a peculiar shining appearance. The method of manufacture was long kept secret. Gahn observed that the spangles consist of metallic copper, crystallized in the form of flat segments of a regular octohedron. Fremy and Clemandot succeeded in preparing this glass, by fusing together for 12 hours a mixture of 300 parts pounded glass, 40 parts of copper scales, and 80 parts of iron scales, and afterwards cooling the mixture slowly. The glass obtained was somewhat dull, but it contained copper diffused through it in octohedral crystals.

To Mr. Pellatt also do we owe the invention of the method of ornamenting glass with delicate white Argentine incrustations of dry porcelain clay, cemented into the solid glass. The figures, made thoroughly dry, are placed on a red-hot bulb of flint-glass, and immediately covered with a thin layer of very fluid glass, so as completely to enclose the incrustation. The polishing of the exterior layer gives the white figure a silvery appearance. The incrustation may of course be coloured before being applied to the glass. Flint-glass vessels with coloured enamel figures on the outside, are sometimes prepared by placing the enamel figures in their proper position in the mould in which the glass is blown. The hot glass firmly cements the figures to the surface.

SECTION X.—BOTTLE-GLASS.

This is the coarsest variety of glass that is manufactured. Formerly, when the duty was only one-eighth that of flint, the law required that wine and beer-bottles should be made of the coarsest materials, such as soap-boilers' waste, and common river or sea sand. Now that the manufacturer is released from the onerous infliction of the excise, he acts to a certain extent according to its old traditions. His glass is not very uniform in character, nor are his materials very pure. But theoretically the basis of bottle-glass is a triple silicate of soda, alumina and lime. The place of a portion of the lime is generally occupied by magnesia and protoxide of iron, and part of the alumina by peroxide of iron. The alumina is in the form of clay. The raw materials are fritted in arches attached to the principal furnace. A very high temperature is required for vitrification, on account of the small proportion of alkali. In 18 or 20 hours the vitrification is generally complete; the glass-gall is skimmed off, and the glass cooled down to the blowing consistency. A wine-bottle is formed in a cast-iron or brass mould, as in the case of flint-glass bottles, and in English wine-bottles the mark of the mould is generally too prominent. Large round bottles are blown without the use of a mould, and when of considerable size, as in the case of carboys for sulphuric acid, the aid of steam is called in; the man spirts a mouthful of water into the interior of the globe which he is blowing, and placing his thumb over the mouth of the blowing tube the water flashes into steam, the elastic force of which acting equally in all directions distends the glass to the required size of the carboy.

Wine bottles require care in the mode of manufacture, according to the class of wine which they are to contain. If the lime or other alkali of the bottles be in excess or not chemically combined, and the wine be of an acid character, the bottle will be slowly disintegrated. If dilute sulphuric acid be kept for a length of time in English-made wine bottles, it will often happen that the interior of some of them will become covered with pustules growing out into the bottle, in consequence of the acid combining with the lime in different points, where it is not chemically combined with the other materials. In this way the bottles may in course of time be drilled through and the contents emptied. We have examined bottles in all these conditions. Bottles containing a fermenting wine should be very strong. The wine-growers of Champagne lose 15, 20, and even 30 per cent. of bottles of wine from bursting by internal pressure. In the Great Exhibition, bottles were exhibited by MM. de Violaine, of Vauxrôts near Soissons: these bottles are much used in Champagne, and it is said that they are all calculated to resist an internal pressure of 25 to 35 atmospheres, (*i.e.* from 25 to 35 times 15 pounds on every square inch of internal surface,) as proved by a machine constructed for the purpose.

SECTION XI.—STATISTICS.

Glass being now free from the trammels of the Excise, we are happily spared the disagreeable task of pointing out the national and individual loss and injury arising from the imposition. We hope before long to see every other description of British industry set free from all Government interference. Our future progress requires it, and we believe that it would be greatly to the advantage of all classes to pay taxes on property rather than have them levied on industry.

Great Britain possesses all, or nearly all the materials required for glass-making, and has abundance of cheap fuel. Hence she possesses peculiar advantages for the manufacture. It would therefore be supposed, that with a drawback on her exports she would long since have supplied a large portion of the world with glass. That such is not the case arises from the fact, that the excise laws did not allow us to enter into fair competition with other nations, or so to improve the manufacture at home, as to keep pace with an increasing population. Thus, according to Mr. Porter,[1] in 1801, with a population of 16 millions, the quantity of glass used was 325,529 cwts., and in 1833, with a population of 25 millions, the quantity was no more than 363,165 cwts.; an increase of less than one-eighth, while the population had increased in the proportion of one-half. Between 1827 and 1845, in which latter year the excise duty was repealed, some improvement took place in the modes of manufacture, so that articles in common use were within that period reduced in price as much as 25 per cent.

In the years 1859, 1860, and 1861, the declared values of the exports in glass of British manufacture were as follows:—

	1859.	1860.	1861.
Flint-glass	£178,220	£222,380	£219,374
Window-glass	39,795	44,071	47,440
Bottles, green or common	327,359	324,181	274,840
Plate-glass	61,181	62,566	47,653
Total . . .	£606,555	£653,198	£589,307

In 1844, the year before the duty was repealed, and with all the advantage of a drawback, our exports in glass were of the declared value of £[illegible] only.

GLAUBER SALT, named after its celebrated discoverer, who, although an alchemist, enriched true chemistry with a number of valuable discoveries. Thus, he discovered muriatic acid by the action of sulphuric acid on common salt, and from the residue of that operation he obtained Glauber-salt, or *sal mirabile*, the sulphate of soda of modern chemistry. See SODA.

GLAZING is the art of fixing glass in the frames of windows. The glass is made secure by means of putty, which consists of whitening and linseed oil. The glass is cut by means of the diamond, as fully described under CUTTING, page [illegible]. Ordinary crown-glass is slightly convex on one side and concave on the other. In glazing windows the effect is much more pleasing to the eye when the convex surface is turned outwards, than when the reverse is the case. British plate or flatted glass is now taking the place of crown-glass, the larger sheets of which are likely to be much in request since our windows as well as our glass have been happily freed from taxation. For GLAZING, see also POTTERY and PORCELAIN.

GLOVES. The manufacture of gloves is not by any means of recent date; but the ancient use of this article of dress was rare and occasional, whereas the modern use is common and almost universal. The ancient Persians wore gloves, and this was cited by Xenophon as a proof of their effeminacy. The father of Ulysses, according to Homer, wore gloves while working in his garden, to protect his hands from thorns. The Romans wore gloves, and were railed at by philosophers for so doing. In the first century of the Christian era it was noted as "shameful that persons in perfect health should clothe their hands and their feet with soft and hairy coverings." Nevertheless, the use of gloves progressed in the world, as we find from various regulations concerning them. They also came to bear part in solemn ceremonials. Possession of lands or dignities was conferred by delivering a glove; deprivation was signified by taking away gloves; challenges were offered by throwing down gloves. Their value in the colder climates caused the familiar use of gloves to go on increasing, but they do not appear to have been adopted in English female dress until after the Reformation. The gloves worn by ladies in the reign of Queen Anne were richly worked and embroidered. Our French neighbours have sought to connect the history of gloves with religion, by affirming that St. Anne, the mother of the Virgin Mary, was a knitter of gloves, and that on account of this her occupation, workpeople of this class have placed themselves under her protection, so that she is invoked to this day in the principal seats of this manufacture in France, and especially at Grenoble, where the feast of St. Anne is observed with great solemnity. This account of St. Anne's employments is prefaced in our French authority by the words, "Scripture informs us that St. Anne," &c.; but it would be a vain attempt to seek for such information in Holy Writ.

The principal materials used in the glove manufacture are leather, silk, cotton, and worsted. Leather, when prepared for this purpose, undergoes a much lighter dressing than when prepared for boots and shoes. The great seat of the glove-trade in England is the city of Worcester and its neighbourhood. Prepared leathers are frequently sent to that city from Bermondsey, and the processes of cutting them up into the proper shape and size, and distributing them to the work-women for sewing, form the employment of numerous firms. France has long been celebrated for its glove-manufactures; but previous to the year 1825 the importation of leather gloves into England was forbidden under heavy penalties. While this prohibition lasted, English gloves were very inferior in quality and high in price; but on its removal in that year, and the admission of foreign gloves at a fixed duty, the improvement in our manufacture was marked and rapid, while the sale of English goods was not diminished. There are certain particulars, however, in which the French continue to excel us greatly in the manufacture of gloves. Some of these will be noticed in the following sketch of the processes.

The first operation in glove-making is to stretch out

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(1) Progress of the Nation, London, 1847.

on a piece of marble, and render uniform with a blunt knife, (shown in Fig. 1095, No. 1,) the surface of the skin of which the gloves are to be made; after which it is to be reduced into pieces of convenient length and width, without cutting the material to waste. Before cutting, however, the skin is made damp, either by rubbing it with a wet cloth, or by putting it in a damp place. It is then sounded, and examined with a view to the discovery of faults or blemishes, so that they may be avoided in cutting out, or at least that they may be so placed as to be unimportant. The skin is then placed so that the width of the glove may be taken across its narrow part. There are regular scales of sizes for men's and women's gloves, and for the width of the thumb-pieces, which are cut out at the same time, and are proportioned to the particular size required. In order to cut the skin to the best advantage, it is stretched from time to time by pulling it at the edges, between the thumb and the knife. When it has been thus elongated and spread out to the utmost, the actual cutting process commences: and here it is, we are told, that the French glove-makers have a great advantage over the English. The former are exceedingly skilful in turning the skins to good account. In cutting up a dozen skins of equal size, a Frenchman will generally manage to get one or two pairs of gloves over and above the number which an Englishman can cut out from the same skins; and these, not inferior, or scanty, but well and handsomely shaped as the rest. This clever and adroit manipulation of the leather is an object of great importance in France, where not less than 375,000 dozens of skins of all kinds are cut up into gloves every year. The shape of the gloves to be cut out is not the only thing to be attended to; great care must be taken that the same shade of colour prevails throughout each pair, for it frequently happens that there are cloudy spots and gradations of colour in the skin, which would be destructive of beauty and good effect. The first operation is to cut the skin longitudinally into two parts, as in No. 2. A piece being divided of the proper width and length for the hand, as in No. 3, is spread out and adjusted, and then carefully folded in two longitudinally, in such a way that a little more width shall be allowed for the back than for the front of the glove. See No. 4. This is necessary, in order that the thumb may have room to move freely, and that there may be proper freedom to the back of the hand when the hand is closed. The want of sufficient allowance in this respect is soon proved by the splitting of the backs, which is such a frequent and annoying occurrence with cheap gloves. The next thing is to make, at fixed distances apart, the three longitudinal cuts which are to form the four fingers. The workman makes his own middle finger a measure for the length of the principal cleft in a man's glove, allowing a little over for the taking up of the leather in working. See No. 5. The width apart of the clefts is regulated by the fact that the first and fourth fingers will have gussets or strips of leather inserted only on their inner sides, while the middle and third fingers will have gussets on both sides. These gussets are carefully cut out, as are the thumb-pieces, from the pieces of the skin remaining over and above from the cutting of the gloves.

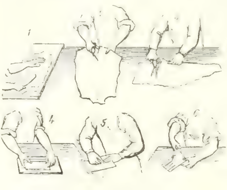

Fig. 1095.

Unless economy is used with all these pieces, it will often happen that a new skin of leather will have to be cut into for the inferior parts, and thus waste will ensue. The forms of the thumb-piece and gussets are shown at *a* and *c* in Fig. 1096. To facilitate the movement of the fingers, there are also small angular pieces, *d*, inserted at the base of the finger, towards the palm of the hand. No small skill is required in cutting out the hole in each glove which is to be filled by the thumb-piece. There is a prescribed, and slightly oblique position in which this hole is to be made, (see No. 6, Fig. 1095,) but as it is necessary it should correspond in form with the peculiar shape of the thumb-piece, it is perhaps the most delicate part of the whole operation to give the exact turn of the scissors which shall produce the desired result. A defect here is often visible in badly made gloves: either the hole is too small for the thumb-piece, and the latter is slightly puckered in putting it in, or it is too large, and the contrary plan has to be resorted to, or it is altogether badly shaped, causing an uncomfortable strain, and a speedy fracture. The form of the aperture varies in different workshops, but the general shape is somewhat as represented at *b*, Fig. 1096. The increasing employment of machinery in the cutting out of gloves promotes uniformity. At the Exhibition of 1851, a French manufacturer (Jouvin, *Boulevard Poissonière*, Paris) exhibited a number of punches for cutting out gloves.

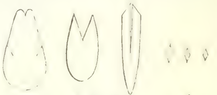

Fig. 1096.

The glove, which now begins to assume its proper form, is next to have the fingers rounded to the proper length, and the back embroidered, when it is ready to be sewed. The sewing of gloves requires more care than that of any other material, especially at the extremities of the fingers, where the joins must be perfectly accurate, and where the closeness of the sewing may, without great care, tear away the delicate leather of the glove. There is a particular order to be observed in the sewing of gloves. The first care is to get the thumb-piece nicely put in, and to correct, as well as may be, any little irregularity which may occur in the fitting of that piece to its place. The outer part is first sewed, arriving afterwards at the tongue-piece which adapts it to the movements of the hand. When this is completed, the glove is folded together, and the long seam is commenced, which reaches from the wrist to the top of the little finger. A gusset is then taken and inserted, the sewing being carried along the outer seam of that and the rest of the gussets, towards the back of the hand. When in this way the fore-finger is arrived at, the gussets are shaped at the top, and the sewing of the inner seam towards the palm of the hand is commenced, the little triangular pieces being duly inserted at the base, for the sake of giving greater freedom to the action of the fingers. All that remains to be done is to make a strong hem round the wrist, and to add a button and button-hole, if it be a glove of the description requiring it. The sewing of gloves may also be effected by machinery.

A machine, Fig. 1097, was largely employed in the sewing of gloves in Paris previous to the invention of the Sewing Machine. [See Appendix.] It consisted of an iron vice A A made fast to the edge of a bench or table B, by a thumb-screw C, armed with a cramp which lays hold of the wood. The two jaws of the vice have their upper portions made of brass, and tipped with a kind of comb of the same metal. The teeth of this comb, only one-twelfth of an inch long, are perfectly regular and equal. Of the two jaws, composing the machine, one, D, is made fast to the foot A A, but the other, E, is movable upon the solid base of the machine, by means of a hinge at the point F. At I I are indicated the points of junction between the brass and the iron. At the bottom of the figure is a front view of the comb as it appears when mounted on the vice, to which it is secured by screws. The lever K corresponds by a stout wire, L, with a pedal pressed by the needlewoman's foot, whenever she wishes to separate the two jaws, in order to insert between them the parallel edges of the leather to be sewed. These being firmly fixed, the woman passes her needle successively through all the teeth of the comb, and is sure of making a regular seam in every direction, provided she is careful to make the needle graze along the bottom of the notches. As soon as one seam is finished, she presses the pedal with her foot, the jaws start asunder, and she adjusts another seam. The vices may be mounted with combs of various shapes, according to the nature of the work. This machine is the invention of an Englishman, and has obtained great praise among the best glove-makers of France.

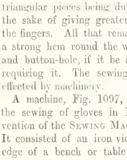

Fig. 1097.

In a machine for sewing and pointing leather gloves, patented by Mr. J. Winter, an arrangement is made for readily removing the jaws of the vice, and adjusting others in their place. This effects a saving of time, for while one person is sewing, another can be preparing and placing the next seam. There are also modifications of the comb, adapted to different methods of sewing and stitching the seams. These contrivances, however, yield to the sewing machine.

GLUCINUM (Gl. 4·7), a rare metal obtained from the emerald, or the beryl, which consists chiefly of alumina and glucina. The metal is procured from the chloride in the same way as ALUMINUM. [See Appendix.] It is a white malleable metal, fusing below the melting point of silver. The oxide *glucina* (Gl.O), is an earth resembling alumina. Its salts have a *sweet* taste, whence its name, from γλυκὺς.

GLUE, see Gelatine.

GLUTEN, see Bread, page 175.

GLYCERINE, see Candle, page 288.

GLYPTOGRAPHY, see Electro-Metallurgy.

GNEISS, a rock abounding in metallic treasures, and the oldest of the stratified rocks. It is composed of the same substances as granite, viz. quartz, mica, and felspar; but they are not in *granular* crystals, but in scales, so as to give the mass a slaty structure.

GOLD. This beautiful substance has been long ranked as the most precious, as it is also the most imperishable and easily worked of metals. It is more generally distributed than any other metal (iron only excepted); but, for the most part, it occurs in such minute quantities as either to escape notice, or not to be worth the pains of extraction. Until recent times, the search after this metal was one of the most precarious and disappointing of human pursuits, and its discovery frequently involved the ruin of the individual, either through the necessary outlay in the commencement of mining operations, or in the improvident habits which the prospect of sudden wealth was apt to induce. We learn from the only infallible source, that gold existed in that part of the earth's surface which was first prepared as the dwelling of man. So, likewise, in all his subsequent wanderings, gold became man's coveted possession, and tokens of its presence were from time to time discovered in nearly all lands. Yet so comparatively small were the gatherings of the precious metal, that in reckoning the average produce of all parts of the New and Old world for a series of years previous to 1847, it did not amount to the annual value of five millions sterling. In that year, however, the first of a series of discoveries was made, which led to a vast increase in the supply of gold, and to a complete reversal of old ideas respecting the prospects of the gold-hunter. These discoveries, forming as they do a grand topic of interest in modern times, will first claim our attention.

In the map of North America, the long narrow peninsula of California, washed by the Pacific, and fenced in with rocky barriers, excited very little interest until the year 1847, when it rose into sudden importance as the El Dorado of modern times. In the greater portion of the mountainous ridge which protects the western coast of California, there are few important breaks or gaps, so that the valleys in the interior are in a great measure isolated; the more so, as an inner range of mountains, running in the same direction as the outer, (nearly north and south,) combines to shut up the particular district to which we refer. The most important opening in the coast-ridge occurs at a place called San Francisco, where the rivers of the interior find outlet in a noble harbour. Two important rivers, having an exactly opposite course, and each receiving the waters of many tributary streams, here unite to pour their waters into the Pacific. These rivers are the Sacramento, flowing from the north along the valley formed by mountain ranges, and the San Joaquim, flowing from the south along the same description of valley, enclosed by the Rocky Mountains on one side, and by the coast range on the other.

It was in September, 1847, that the first symptom of gold in this region was discovered, on the property of an intelligent Swiss emigrant, Captain Suter, who had become a wealthy settler on the banks of the Sacramento River, was possessed of large flocks and herds, owned trading vessels, and had built an important fort, called New Helvetia, for the defence of his property. The state of the country, and the absence of lawful authority, may be judged of by the fact, that he found it necessary to supply his fort with twelve pieces of artillery, and a garrison of seventy men.

It was in the course of the erection of saw-mills on this estate that Mr. Marshall, the contractor for the building of the same, observed glittering particles in the mud of the stream, and communicating the information to his intelligent employer, the value of these particles was quickly ascertained. The workpeople soon became aware of the discovery, and the town of San Francisco speedily yielded nearly its whole population in the exciting search for gold. The supply was beyond all expectation great, and the consequent rush of emigrants of all nations to share in the riches is well known. Various were the evils arising from this influx of strangers in a half-civilized country, and still more various were the prophecies of ill to the world at large. In England it was commonly thought that this sudden gold-harvest would demoralise industry, and throw the great machine of commerce out of order, and that, after all, the supply would be very soon exhausted. This last idea, however, has proved unfounded. Every new account from this wonderful coast seems to extend the range of the gold-seekers. Gold is found in the excavations of the mill-race, and in the mud of the river; accumulated in gulleys, and diffused over plains; set deep in quartz, or mixed with crumbling granite. "It was found in digging a well at San Francisco; and then, a hundred miles off, it was dropping from cliffs into the sea, and slowly settling through the sands of the shore. The searchers have to dig pits, to climb mountains, to turn rivers, to sink shafts, to run galleries, to uncover plains, to break, to crush, to roll, to shake, to wash, to amalgamate." One discovery quickly supplants another, and one set of implements quickly yields to another. At one time a rocking-machine for separating the gold was in great demand; but before our manufacturers could send out a supply, it was superseded by a cradle of ingenious construction. Then came crushing-mills of various kinds, for pounding the auriferous quartz of Mariposa. An immense amount of machinery has been sent out for this purpose, and will doubtless be turned to good account; but the most recent accounts from California speak of discoveries which offer gold without the use of tools or machines other than the common implements for turning up the soil; for the precious metal in this case lies in a soft greasy slate, easily to be crumbled between the fingers. The slate is thickly interspersed with extremely fine particles of gold, which are separated by means of quicksilver. At a spot appropriately named Mount Ophir, fine specimens have been met with, of "soft clay and slate saturated with gold, small particles and large lumps." These treasures lie from 10 to 30 feet below the surface, so that a great deal of top dirt has to be thrown up before the slate is reached. Seven Mexicans, who made this discovery, and kept their secret eight days, made in that short time 217,000 dollars. One lump might yield three dollars, another twelve dollars, and so on. Other searchers, from a shaft twenty feet deep, obtained the soft clayey slate in buckets, and found from eight to twelve dollars' worth of gold in each bucket. This new discovery comes within the limits of the "diggings," and falls under what is called "placer" law; that is, every man who comes may claim his thirty feet square, and set to work as he pleases, without asking the landowner's leave. If he wanted to plant mills, and make expensive mining works, he would have to obtain a grant of the soil. A great number of persons were soon congregated in the new diggings, and a flood of gold seemed to threaten the European market. From the great Californian field of enterprise, thirty millions of gold in a few years found their way into the commercial world, without producing any very striking or marked effects; but if this rate of produce continued, it was thought there must eventually be produced corresponding alterations in monetary matters.

While the attention of the whole world was directed to the golden land of California, a new announcement was made, in which England had a special interest; namely, that gold was discovered in her Australian possessions. And certain it is that the year 1851, memorable to this country in many other respects, was also memorable from the fact that Australia then began to reveal her long hidden treasures. The first discoveries were made near Bathurst, which is situated upwards of a hundred miles west of Sydney, New South Wales. They are due to Mr. Stutchbury, a geologist employed by Government, and Mr. Hargraves, a gentleman who had long been familiar with the geology of the Blue Mountains. The latter washed out gold from several baskets of earth, and soon organized a body of persons to assist in his labours. Similar results to those in California soon followed; only that in this case the law afforded its protection to the gold-searchers, and the whole affair was early put under Government inspection. Gold was found with surprising facility. lumps of the pure metal were picked up; and a poor man, who went to the diggings with only a forked stick and an old frying-pan, raked up five pounds' worth of gold in half a day. Two thousand persons had speedily established themselves at the Ophir diggings, (for again we have the propitious name,) and one large specimen of pure gold had been found, weighing forty-six ounces. Meanwhile, a Government proclamation taught the people their relations to the mother country, as it respected the new discoveries: viz. that all gold-mines in the British dominions belong by law to the Crown; that no gold was to be removed from the leased lands without Government permission; and that licences were about to be granted to gold-seekers, at definite fees or royalties, and under definite arrangements. The fees amount to thirty shillings a-month.

But the Australian gold-field was not confined to a few rivers in the neighbourhood of Sydney and Bathurst. Wonderful news reached England of deposits further south, surpassing all that had been told of Sydney, and even California. At a place called Buninyong, about eighty miles from Melbourne, and fifty from Geelong, eight feet square, instead of thirty feet square, of digging ground was supposed to be enough to make a person's fortune. One man had found fifteen hundred pounds' worth of gold in one week,—another man a thousand. A party of three men had met with twenty pounds' weight in one day, while another before breakfast raised thirteen pounds' weight. Thus Melbourne and Port Philip became even more attractive than Sydney. The whole neighbouring population were moving towards the gold district, and a far greater desertion of general employments had taken place than had been witnessed at Sydney. Hundreds of all classes were hastening to Buninyong, including labourers, mechanics, clerks, shopkeepers, merchants, and professional men. There was hardly any possibility of getting ships' crews; and the ship which first conveyed the intelligence to Bombay was only enabled to sail by obtaining her complement of men from among the seamen confined on short sentences in Melbourne gaol. Even that was attended with difficulty, for only six could be found who did not prefer stopping in confinement, on the chance of getting afterwards to the mines. A government escort had arrived with 17,000*l*., and was to return for a further sum of 20,000*l*. The metal is found at considerable depths; and, in order to obtain it, "a hole is dug, ten or twenty feet deep, through black alluvial soil, sandy gravel, and clay of various colours, until a very thick substratum of pipe-clay is reached. Immediately above this is, in places, a stratum of chocolate-coloured clay, in which the gold is not only perceptible, but conspicuous; and one man sits in the hole and picks out the rich stuff with a knife, while his companions with a cradle work the earth which has been thrown out.

Thus we appear to have an abundant, accessible, and wide-spread supply of our own, in addition to the great gold-fields owned by America, and open to all emigrants. And it is impossible to say how many more gold-regions may now come to light, inviting the population of crowded Europe to new homes, and wider spheres of action. Many a swarm will be sent off from the parent hives, and many a new community will spring up in the gold-countries. Let us hope that, as the golden harvests have been bestowed on the only two free nations of the earth—the United States and the British Empire—their children will use the dangerous gift with discretion, remembering that wisdom "cannot be gotten for gold, neither shall silver be weighed for the price thereof."

In connexion with the Australian discoveries, it is a remarkable fact, that Sir R. Murchison foretold them in 1845, when he compared the eastern chain of Australian mountains with the Ural. In 1846, he even recommended the unemployed Cornish tin miners to emigrate to New South Wales, and dig for gold in the debris and drift of the Australian Cordilleras. In 1847, he received letters from speculators in Sydney and Adelaide, sending specimens of gold which they had sought and obtained in consequence of his writings; whereon Sir R. Murchison wrote to Earl Grey, informing him that his anticipations were about to be realized in a manner which might operate a great change in the colony. His views were further embodied in the *Quarterly Review*, 1851. The Rev. W. B. Clarke, also, in examining the geological structure of the Blue Mountains of Eastern Australia, as early as 1841, "was attracted by the plutonic and metamorphic character of the axis of the range, and by the presence of gold in the quartzites and in the detrital accumulations derived from the axial formations, evidence being afforded of the existence of gold within eighty and sixty miles of Sydney." By subsequent researches, Mr. Clarke was convinced that "copper, lead, and gold are in considerable abundance in the schists and quartzites of the Cordillera" (Blue Mountains).

These discoveries, though of paramount interest, must not make us forgetful of the state of gold-mines previous to 1847. Let us first describe those of Europe. There are not many countries totally without traditions of gold, and in the British Isles, these have at various times appeared to promise substantial results. In the alluvial soil of Leadhills in Scotland extensive washings for gold were carried on in the time of Queen Elizabeth. The precious metal was also found to occur at Glen Turret in Perthshire, and at Cumberhead in Lanarkshire. The stream-works of Cornwall also yielded gold, and towards the close of the last century the most promising accounts were given of gold in Ireland. In fact, the peasantry in the neighbourhood of Ballinavalley River, County Wicklow, did gather, in the course of two months, an amount of gold for which 10,000*l.* were paid; but on the government undertaking the search, it proved that the supply was very soon exhausted, considerably less than four thousand pounds' worth being collected in the course of two years. This did not pay the necessary expenses, and the works were abandoned. The gold, as at first collected by the people, occurred in massive lumps, and in small pieces, down to the minutest grain. Pieces of 7, 9, 18, and 22 ounces were found, and these occurred dispersed through a kind of stratum of clay, sand, and gravel, covered by soil which sometimes was of considerable depth, from 20 to 50 feet in the banks of streams. Recently, some energetic proceedings have been commenced, and workings established on a large scale for the discovery of gold in North Wales. [See APPENDIX.]

On the continent of Europe, leaving Russia for the moment out of the question, Hungary and Transylvania furnish from the sands of their rivers the chief supply of gold. The annual produce of Hungary is stated at 2,810 lbs. weight, and valued at 176,000*l.* The mines of Spain were anciently rich and valuable, but are now entirely neglected. This is the case also with the sands of the Danube, the Rhone, the Tagus, and many other European rivers, which possess gold in small quantities, but are rarely worth the expense of working. In the valley of the Rhine, indeed, between Basle and Mannheim, gold is found in little flakes accompanied with titaniferous iron. The gold spangles are exceedingly minute and thin, so that it takes from 1,100 to 1,400 of them to make a grain troy. They appear to be derived from the crystalline schists and other rocks of the High Alps.

The gold mines of Russia, which are the most considerable in the Old World, must come under the head of Asia, as they are situated to the east of the giant barrier formed by the Ural Mountains. During the century previous to 1841, the mines of Berezovsk in the neighbourhood of Ekaterinburg, yielded about 24,500 lbs. weight (avoidupois) of gold. In general the matrix consists of coarse gravel, but there are true auriferous veins enclosed in a band of rock, in which are many veins of quartz with gold disseminated. From these veins the valuable portions are extracted by vertical shafts and lateral galleries, and this is the only instance in the Russian territory where gold is extracted by the aid of subterranean workings. Much more generally the gold is found in fragments of rock which cover the earth to a considerable thickness, and is associated with other metals, as platinum and palladium. The quantity of gold obtained from the Russian mines has been greatly on the increase of late years. On the Asiatic side of the southern portion of the Ural mountains, sands of immense richness were discovered in 1842. Great success attended the search for gold throughout an extensive marshy plain near the site of former gold-mines, on the banks of the river Tachnou-Targanna. The whole valley had been searched except the part of it occupied by the buildings in which the washing operations were carried on. In the year named it was decided to remove these houses, whereupon not only were rich sands discovered, but under the corner of a building, at the depth of three yards, an enormous mass of gold was dug up, weighing upwards of 36 killogrammes, about 80 lbs. English. This mass was placed in the collections of the Corps des Mines at St. Petersburgh. A mass had been found in the same neighbourhood in 1836, weighing upwards of 22 lbs. English. It is not, however, usual to find large lumps of gold in the Ural districts, the fragments being commonly of small size, and only separated by washing, the yield seldom exceeding 36 grains of gold per ton-weight of soil, and never in ordinary cases more than 70. The sand of any river is considered worth washing for the gold it contains, provided it will yield 24 grs. per cwt., but the sand of many streams yields many times this proportion. In the eastern group of deposits, near the Altai Mountains, it is said that over a district as large as France, not only are considerable quantities of gold found mixed with sand and gravel on the surface, but even the rocks themselves, when pounded up, are found to yield a per-centage of that precious metal. The gold alluvia of Russia were known in the days of Pallas, and supposed to exist only near Ekaterinburg; in the reigns of Paul and Alexander they were found to extend, in a certain zone, to the north and south of that locality, and eventually half a million sterling was extracted from them annually. "The reign of the Emperor Nicholas," says Sir R. Murchison, "has been distinguished by the important discovery, that portions of the great *eastern* regions of Siberia are highly auriferous, viz. in the governments of Tomsk and Yeniseik, where low ridges, similarly constructed to those of the eastern flank of the Ural, and, like them, trending from north to south, appear as offsets from the great east and west chain of the Altai, which separates Siberia from China; and here it is curious to remark, that a very few years ago, this distant region did not afford a third part of the gold which the Ural produced, but by recent researches, an augmentation so rapid and extraordinary has taken place, that in 1843 the eastern Siberian tract yielded considerably upwards of two millions and a quarter sterling, raising the total gold produce of the Russian empire to near three millions sterling."

Other parts of Asia yield small supplies of gold, as the rivers of India, China, Sumatra, and Asia Minor; and now that the sagacity of the gold-seekers is fully on the alert, it is confidently to be expected that further discoveries will be made in the east.

Africa is at once pointed out by her "Gold Coast" as yielding the precious metal, yet the whole supply from that continent is not estimated at more than 5,000 lbs. weight annually. This includes the produce of the district between Darfur and Abyssinia, where the chief supply is found, the Mozambique coast opposite Madagascar, the Gold Coast, specially so called, and the sands of the rivers Gambia, Senegal, and Niger.

America, long before the discovery of the Californian treasures, had become celebrated for gold mines, both in the north and south. The gold region of the United States extends along the eastern slope of the Appalachian chain of mountains, from the river Rappahannock in Virginia to the river Coosa, an affluent of the Alabama, in the state of that name. This immense stretch of country, bordering on the Blue Ridge, has many advantages over gold producing countries in general, owing to the mildness of the climate, the abundance of food, and the security which it offers to life and property. The most productive mines are in Virginia, North and South Carolina, and Georgia; but the gold region extends even to Canada, where the search for the precious metal is being carried on with some vigour at the present time. From Silliman's Journal we gain the following particulars of the mines of North America. "In Georgia, the richest mineral belt is in the talcose-slate, and granite formations, alternating with hornblende-slate, gneiss, and chlorite-slate: parallel mineral belts are found also near Augusta, but they cease with the termination of the primitive region. The most productive researches for gold have been made in the branch-streams or stream-mines, in the beds of rivers, rivulets, and ravines. In such cases little capital is needed, and few machines, except rockers, and the return is almost immediate and daily; from 5 to 10 dwts. per day for a single hand are not uncommon, and 120 have been obtained. In the loose deposits the gold is found in a bed of gravel, from 9 inches to 3 feet in thickness, and from 3 to 6 feet from the surface of the ground; it rests on slate, generally talcose, and is evidently the result of the destruction of a vein or veins crossing a watered ravine, or taking the same direction with it. The Burke rocker of North Carolina will wash a hundred-weight (700 to 1,000 bushels of gravel) a-day, and the machine costs, when complete, but 25 dollars. Branch-mines have led to the discovery of many valuable vein-mines, for the miners, working until the gold seemed to fail, would come back and work into the banks or sides of the ravine, guided by the gold, and at last discover valuable beds of gold ore. Many instances of this kind have occurred in North Carolina and Virginia. The branch gold-mines of the United States are supposed to have yielded 6,000,000 dollars, most of which is worked up in jewellery, and not in coinage. The explorations for gold have not as yet been carried to a great depth, the greatest not exceeding 150 feet, and few of the shafts are over 100 feet; most do not exceed 20 or 30. These excavations are too shallow to afford satisfactory information respecting the gold, and the digging is often abandoned on the least unfavourable appearance, such as the narrowing of a vein, its dislocation, or its becoming shattered; for there is much appearance of disorganization in the veins and rocks. Pyritical ores constitute the mass of the ores in Columbia, Brazil, and the United States: above the depth of 100 feet they have been partially decomposed; the yellow ores have been converted into brown, red, and purple hydrates of iron, and a portion of the gold they contain having thus become uncovered, is accessible to amalgamation, while a large portion more is, or can be, developed by the assay by fire. Most of the gold is extracted by amalgamation, after stamping under water, and the residuum still contains gold. A committee from the Geological Society of Pennsylvania closely investigated the Rappahannock gold-mines in Virginia, situated on the river, about 10 miles from Fredericksburgh. The tract is about 230 yards wide, by an average length of 900 yards. The metalliferous veins consist of hard quartzose rock between walls of decomposed talcose slate. A portion of loose red soil, by washing two handsful of it, gave a considerable quantity of minute granular gold; and similar results were obtained by washings in other places. A principal auriferous quartz vein is from 2 feet 6 inches to 3 feet 6 inches wide; it stands vertically between walls of talcose slate. The auriferous quartz vein has been exposed to view for 627 feet, with a width of 30 inches, and it would appear that this is only the beginning. By a rough process of washing, amalgamation, and evaporation of the mercury, three and a half grains of gold were produced from 4 lbs. of the ore taken indiscriminately from all parts of the vein; and in another experiment 5 grains of gold were produced from 4 lbs. of pure milk-white quartz, which had no appearance or indication of containing any metal at all."

In South America gold is found on both sides of the great chain of mountains which runs parallel with the coast. The precious metal is gathered from the beds of streams which take their rise in those majestic heights. It is also found in a stratum of gravel and rounded pebbles at a great depth below the soil, and immediately incumbent on the solid rock. In former times, Brazil was the richest of American gold countries, and the precious metal is still found in more or less abundance, in nearly all the rivers which form the upper branches of the Francesco, Tocantins, Araguay, and Guaporé, but by far the largest quantity is yielded by the affluents of the Francesco. Yet it would appear that their golden sands begin to show signs of exhaustion. The work is, nevertheless, extensively and steadily carried on, and as the sands become exhausted, the mountains are the more diligently explored for the rich veins which often exist in their recesses. The greatest quantity of gold was obtained from Brazil between the years 1753 and 1763, and since that time it has always been on the decrease. This is not entirely owing to the impoverishment of the auriferous sands, but also owing to the want of capital to work the veins in the mountains on a regular system. British capital has at length been brought to bear on the undertaking, and the productive mines at Congo Soco, on the banks of the Rio das Velhas (a tributary of the Francesco) are the result. In addition to the Brazilian mines there are gold veins and washing for gold in Peru, and in other parts of South America; but all yield in importance to those we have named.

Gold (Au 196.6) has a characteristic yellow colour. Its specific gravity in its least dense state after fusion is 19.2; by hammering and rolling it may be brought up to 19.3, or 19.4, or even, according to Berzelius, to 19.65. It fuses at a bright red, or a white heat, the temperature of which has been estimated at 2016° Fahr., and when in fusion, it is of a brilliant greenish colour: it contracts on cooling, and when the operation is slowly conducted, it forms short quadrangular pyramidal crystals. It is volatile at very high temperatures. A gold wire is reduced to vapour by the discharge of a powerful electric battery; and if the wire be placed just above the surface of a sheet of paper, the course of the discharge is marked by a broad dark purple stain, produced by the finely divided gold. If the paper be covered with silver leaf, the latter is gilt by the discharge. A globule of gold gives off abundant vapours when placed between the terminal charcoal points of a powerful voltaic battery. Gold is the most malleable of all the metals: it may be extended into leaves which do not exceed $\frac{1}{200000}$th of an inch in thickness, or a single grain may be extended over 56 square inches of surface, or be drawn out into a wire 500 feet long. The extensibility of gold is well illustrated by the process of gilding buttons, 144 of which are well gilt with 5 grains of gold, and in many cases only half that quantity is used. [See BUTTON.] Réaumur, by rolling out a fine silver-gilt wire, reduced the coating of gold to the twelve millionth of an inch in thickness, and the surface appeared to be perfect when viewed under the microscope. Gold, precipitated chemically, forms a brown powder, which under the burnisher readily assumes the metallic lustre and characteristic colour of malleable gold. This precipitate also admits of being aggregated or welded together by percussion; and if heated to redness before being hammered a second time, the metal becomes perfectly aggregated, without having been raised to its point of fusion. Gold does not combine directly with oxygen at any temperature. Sulphuric, nitric, and muriatic acids do not act upon pure gold; neither does sulphur: nor is sulphuretted hydrogen decomposed by it. Chlorine and bromine attack it easily at ordinary temperatures; iodine exerts only a weak action upon it. Nitro-muriatic acid [See AQUA REGIA] dissolves gold with ease. It is also dissolved by muriatic acid, if a substance be added thereto capable of liberating its chlorine, such as peroxide of manganese, chromic acid, &c.

There are two oxides of gold: a protoxide (AuO), and a teroxide (AuO_3), also known as *auric acid.* There are two chlorides: the protochloride ($Au\,Cl$), and the terchloride ($Au\,Cl_3$) This last is produced when gold is dissolved in nitro-muriatic acid. When a solution of protosulphate of iron is added to perchloride of gold, the mixture acquires a dingy brown tinge, and if very dilute, a green or blue, as seen by strong transmitted light, an effect due to the presence of numerous small particles of gold in the metallic state: they quickly subside in the form of a brown powder, which, after having been washed in boiling water, digested in hot dilute muriatic acid, and again washed and dried, forms pure gold, in which state it is used for gilding porcelain. Perchloride of gold dissolves in alcohol and ether; polished steel dipped into the solution acquires a coat of gold; delicate cutting instruments are gilt in this way.

When a very dilute mixture of protochloride and perchloride of tin is dropped into a dilute neutral solution of perchloride of gold, a flocculent purple deposit takes place, known as the *purple of Cassius*, from the name of the discoverer, Cassius of Leyden, 1683. The nature of this compound is not well understood, but it is supposed to consist of a hydrated double stannate of gold and tin ($AuO,\ SnO_2 + SnO,\ SnO_2 + 4Aq$). This powder may be separated, not by filtration, but by adding a salt to the liquid and boiling it. It is soluble in ammonia, the solution being of a deep purple. It is decomposed by the acids and also by heat. Purple of Cassius is used in enamel and porcelain painting, to which, mixed with borax, it imparts a beautiful rose or rich purple colour. It also gives colour to the red glass of Bohemia.

The addition of liquid ammonia to chloride of gold gives rise to a yellowish brown precipitate, aurate of ammonia, or fulminating gold. It explodes at a moderate heat, by friction, or an electric shock. This compound has no application in the arts, nor, indeed, have the other compounds, except those which have been named in this article, and in the process of electro-gilding. [See ELECTRO METALLURGY.]

The addition of an inferior metal to gold tends only to degrade the noble metal; hence the alloys of gold are of very little importance in the arts, with the exception of those formed with silver and copper, which tend to increase the hardness and durability of gold. Silver confers a pale greenish colour on gold. English standard gold contains $\frac{1}{12}$th of alloy, which is now always copper. [See COINING, Ap.]

Different shades of *colour* are given by the jeweller to ornaments of gold by exposing them to different chemical agents, which dissolve out a portion of the copper and silver alloy, while they have scarcely any action on the gold. By this means, the surface of the ornament is made to appear like pure gold; while below the surface the quantity of copper or of silver may be considerable. The French jewellers possess a number of recipes for giving colour to gold, the most common of which is a mixture of two parts nitre, one part sea-salt, and one of Roman alum. Of this mixture a quantity is taken about three times the weight of the jewels which are to be coloured, and a concentrated solution is made with boiling water. The jewels are kept in this solution at the boiling point from fifteen to twenty-five minutes, according to the shade required: they are then taken out, washed in water, and the operation is finished. The surface of the gold is dull, but perfectly uniform, but can be made lustrous by burnishing. They lose about $\frac{1}{16}$th of their weight by the operation. The methods adopted for recovering the metals from the solution, as also from the waste waters of the jeweller, are considered chemically by M. Berthier, in the *Annales de Chimie et de Physique* for 1835. [See METALLURGY and APPENDIX.]

GOLD BEATER'S SKIN. The preparation of animal membranes for various purposes in the useful arts is described in the article CAT-GUT, but we may here state, that after the membrane has been well cleaned in alkaline solutions, it is stretched out on a frame, with the mucous surface uppermost, and another membrane placed upon it in an opposite direction: the two clean surfaces unite readily and firmly. This compound membrane is next prepared with solutions of alum, isinglass, white of egg, &c., and is beaten between folds of paper to expel the grease, pressed and dried; but the routine of the operations cannot be stated very explicitly, as each manufacturer professes to have his own secret. A *mould* of skins, as it is called, is costly, but it will last several months without becoming too thin or weak for use. The leaves become in time unfit for work, but their flexibility is restored by placing them between leaves of white paper, and moistening them with vinegar or white wine; in this state they are loaded with weights, and left three or four hours. When sufficiently moist, they are put between leaves of parchment twelve inches square, and beaten for a whole day. They are then rubbed over with fine calcined gypsum, and are again fit for use. These skins are apt to get damp if neglected, and must be dried before being used.

In the Exhibition of 1851, Mr. Puckridge's Case (Class IV. No. 108) contained a variety of interesting illustrations of the manufacture of gold-beater's skin. 1. The cæcum of the ox, from which the skin is prepared. 2. Various stages of the skin in process of manufacture. 3. A gold-beater's *mould* as used in England and America, containing 850 leaves $5\frac{1}{8}$ inches square (each leaf being double), and $\frac{9}{16}$ths of an inch thick. To produce this requires the slaughter of 500 oxen. 4. The mould used in France and Belgium, consisting of 1,200 leaves, $5\frac{1}{4}$ inches square, to produce which requires the slaughter of 750 oxen.

GOLD BEATING. It is stated under GOLD that gold may be extended into leaves which do not exceed $\frac{1}{290000}$th of an inch in thickness. The proof of this remarkable tenuity is easy. For example, an ounce of gold is equal in bulk to a cube each of whose edges measures $\frac{5}{12}$ths of an inch, so that, placed upon the table, it would cover little more than $\frac{1}{6}$th of a square inch of its surface, and stand $\frac{5}{8}$ths of an inch in height. The gold-beater hammers out this cube of gold until it covers 146 square feet. Now it can easily be calculated that to be thus extended from a surface of $\frac{5}{12}$ths of an inch square to one of 146 square feet, its thickness must be reduced from $\frac{5}{12}$ths of an inch to the 290,636th part of an inch. Gold is often beaten to the 367,650th of an inch, or about 1,200 times thinner than ordinary printing paper; this is not the limit of the malleability, but there are practical difficulties in the way of further reduction.

The gold-beater uses pure gold, mixed with various proportions of silver or copper for the purpose of obtaining different colours, of which there are about thirteen, namely, *fine gold, red, pale red, extra deep, deep, orange, lemon, deep pale gold, pale, pale pale, deep pewly, pewly,* and *white*. The deeper colours are alloyed with copper, the middle colours with silver and copper, and the paler with silver only. The metals are fused together in a crucible, and cast into flat oblong ingots, each about $1\frac{1}{2}$in. long, $\frac{3}{4}$in. wide, and $\frac{3}{16}$ths of an inch thick. Each ingot is then formed into a riband by passing it between two rollers of polished steel, and this laminating process is continued until the ingot is spread out to a surface of 960 square inches of the thickness of rather more than $\frac{1}{800}$th of an inch.

The riband of gold is annealed or softened in the fire, and cut up into pieces of the size of a square inch, and 150 of these are placed by means of wooden pliers between an equal number of leaves of a tough paper of peculiar make, each square of gold occupying the centre of each. A parchment case, open at both ends, is drawn over this *tool*, or *kutch*, as the packet of leaves is called, and this is enclosed in a second similar case, so as to cover the edges left exposed by the first case. This packet is then beaten with a sixteen-pound hammer upon a smooth block of marble, strongly supported from below, and surrounded on three sides by a raised ledge of oak; the front edge is open, and has a kind of leathern apron attached to it for catching fragments of gold that may escape in the subsequent operations. The elasticity of the packet causes the hammer to rebound, and thus lightens the labour of the operator, and enables him to apply his blows with regular effect; every now and then, in the interval between two blows, he turns the packet over to distribute the force equally, and he occasionally bends the packet to and fro to overcome any slight adhesion between the gold and the leaves; and at intervals he opens the packet to see that the work is satisfactory, and also to re-arrange the relative positions of the squares of gold, by placing those near the surface in the centre, and placing these near the surface. The beating is continued until the one-inch squares are spread out into four-inch squares. The packet is then opened, and each piece of gold is taken out, placed on a cushion, and cut into four pieces with a knife. This increases the 150 pieces to 600, and these are put between the leaves of another tool, called a *shoder*, made of gold-beater's skin. The packet is enclosed in parchment, and beaten for two hours with a nine-pound hammer as before. The squares of gold are again spread out to nearly the area of the gold-beater's skin. The packet is again opened, the leaves of gold are again cut into fours, and each quarter is placed between two leaves of membrane as before. The gold is in this case divided by means of the smooth edge of a strip of cane, since it has a tendency to adhere to a steel knife. The squares of gold, now increased to 2,400, are separated into three parcels of 800 each; the squares of each parcel are again separated by gold-beater's skin, confined in the parchment cases, and beaten as before. This forms what is called a *mould*. These squares of gold-leaf expand for the third time nearly to the size of the leaves of membranes, and have at length attained the required degree of tenuity. This last beating requires skill. During the first hour the hammer is directed chiefly on the centre of the mould; this causes the edges of the leaves to crack, but they unite again when beaten. During the second hour, when the gold is 150,000th of an inch in thickness, it allows the light to pass through. If the gold be pure or but slightly alloyed, the transmitted light is of a green colour, but pale violet if highly alloyed with silver. The mould is beaten during four hours with a seven-pound hammer, after which the thin leaves are taken up one at a time with long pincers of white wood, and being placed on a cushion, are blown out flat by the mouth, which requires skill. Broken or injured leaves are rejected; but those which are perfect have the ragged edges cut off, which reduces their dimensions to about $3\frac{1}{4}$ inches square. In this operation a tool is used called a *waggon*, consisting of edges of cane mounted in a frame, the sides of which are $3\frac{1}{4}$ inches apart. Twenty-five of these leaves are placed between the folds of a paper book, the surfaces of which have been rubbed with red chalk, to prevent adhesion, and in this form gold-leaf is sold.

Silver and copper leaf are prepared in a somewhat similar manner to gold. Copper is less malleable than gold, and both it and silver-leaf are thicker; but calculated by weight, it does not appear that gold is more malleable than silver. The silver-leaf used for silvering letters on omnibuses, &c., is really gold largely alloyed with silver. Pure silver-leaf would be liable to tarnish. What is called *dentists' gold*, or that used for stopping teeth, is the gold beaten out from the ingot, then divided, and beaten out once again.

The dryness of the kutch, shoder, and mould are of importance, to ensure which they are placed in an iron press that has been heated at the fire every time they are used. In frosty weather the tools may be over dry, and then the lustre of the gold becomes dimmed, and it spreads slowly under the hammer. If the kutch or shoder be damp, the gold will become *hollow*, or *sieve-like*, that is, it will be pierced with numerous microscopic holes, and in the moulds will pass into the pulverulent state.

GONIOMETER (γωνία, an angle, and μέτρον, a measure), an instrument for measuring the angles at which the planes of crystals incline to each other.

GOVERNOR, or Centrifugal Pendulum, see Steam Engine.

GRADIENTS, see Railway.

GRADUATION is the art of *dividing* mathematical, astronomical, and geodesical instruments. It is the most delicate, difficult, and important branch of the mathematical instrument maker's art, and few persons are gifted with sufficient accuracy of eye and precision of hand to excel in it. By its means an instrument, either by linear or angular measure, is made to determine the dimensions of objects, or their distance from each other. In a vast number of cases the value of the observation depends upon its accuracy; and this, again, upon the correctness of the graduation; and the importance of accurate observation will be at once appreciated from the fact, that a slight error in nautical astronomy may lead to the loss of a ship. In a circle of 3 feet radius, which is that of the mural circle at Greenwich, a minute of a degree is little more than the 100th of an inch, and this quantity, respecting latitude, is the measure of about a mile upon the surface of the earth; but in longitude, as derived from lunar and solar tables, the minute represents upon a mean no less than about 30 miles, while in some of the elements of astronomy, as obtained by observation, the disparity is very much greater.

The invention of the telescope soon led to that of instruments of observation, in which a correct system of graduation became more and more required. Some of the earlier astronomers who used the telescope graduated their own instruments; but before this, in most countries of Europe, clockmakers were the first to fabricate mathematical instruments. Thus the instruments invented by Hooke were made by Tompion, and he and Graham made instruments for the Royal Observatory at Greenwich, the establishment of which led to the production of superior instruments; and successive Astronomers Royal have, from time to time, encouraged the talents of superior artists. According to Smeaton,[2] the first person who cut accurate divisions on astronomical instruments, was Abram Sharp, assistant to Flamsteed. About the year 1689 he constructed and graduated for the Royal Observatory a mural sextant of $6\frac{1}{2}$ feet radius, which did good service to astronomy in the hands of Flamsteed. In the early part of the eighteenth century some instrument makers became celebrated in the art of dividing. Some of the works of Rowley are still extant, and are said to bear evident proofs of neatness and accuracy. A little later than Rowley the elder Sisson constructed and graduated large instruments with success, such as the 8-feet mural, and several large zenith sectors of Graham. About 1727 Bird, a rustic lad of Bishop-Auckland, observing the unequal divisions and coarse engraving of a clock-dial plate, determined to execute one for himself. The success of the attempt attracted notice, and he was enabled, a few years afterwards, to come to London, where he served a short apprenticeship with the elder Sisson, and became acquainted with Graham, from whom he acquired much valuable information. In 1745 he was in business for himself, and he and the younger Sisson were rivals for fame. It is said that the latter was as superior in ingenuity as the former was accurate in execution and sound in judgment. In 1767, at the request of the Commissioners of the Board of Longitude, Bird published his method of dividing, and was rewarded with 500*l*., besides 60*l*. for his plates, he having agreed to instruct an appren-

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(2) The celebrated Smeaton began life as a mathematical instrument maker, and his paper in the *Philosophical Transactions* for 1786 contains a variety of details, which, probably, no one else could have written. Its title is: "Observations on the Graduation of Astronomical Instruments, with an Explanation of the Method invented by the late Mr. Henry Hindley, of York, Clockmaker, to divide Circles into any given number of Parts. By Mr John Smeaton, F R S. Communicated by Henry Cavendish, Esq. F.R S & S.A. Read November 17, 1785."

tice of seven years in the art of constructing and dividing astronomical instruments. About 1740 Henry Hindley, of York, was the first to construct an *engine* for graduating instruments, and which also served to cut the teeth in clock-wheels. In 1768 the Duc de Chaulnes published at Paris his "Nouvelle Méthode pour diviser les Instrumens de Mathématique et d'Astronomie;" also, "Description d'un Microscope et de différens Micromètres destinés à mesurer des parties circulaires ou droites avec la plus grande précision." This method has been considered as the basis of Ramsden's method of dividing a large circle. The last named celebrated artist had the great merit of rendering small instruments almost as accurate as the large ones had previously been, and the graduation of his larger works was superior to any that had been executed. About the year 1766 he constructed a dividing engine, which, although it fell short of his expectations, exceeded in accuracy the best dividing plate. It answered well enough for dividing common instruments, but was not sufficiently accurate for those used in finding the longitude at sea. Ramsden's second effort was much more successful. A sextant, divided by the new engine, was carefully examined by Bird, and pronounced by him to be fit for every purpose of nautical astronomy. Ramsden's engine was well suited to the time in which it appeared,—a time when the improvements in nautical astronomy, and the extension of our commerce, created a great demand for reflecting instruments, which never could have been supplied if it had been necessary to divide them by hand. In 1777, at the request of the Commissioners of the Board of Longitude, Ramsden published on oath an account of his engine, for which he received a reward of 300*l*., and a further sum of 315*l*. on condition of making over his engine to the public, and engaging, so long as the engine remained in his possession, to divide sextants at 6*s*., and octants at 3*s*. each, for other mathematical instrument makers.[1] The instrument makers, however, complained that Ramsden kept their work too long in hand, and that his assistants were very careless. Such complaints as these would be likely to stimulate ingenious men to copy Ramsden's engine now that it was public property. The first to do so was Mr. John Troughton, who, after labouring during three years, with much self-denial and straitened pecuniary means, completed, in 1778, a graduating engine, which soon became the successful rival of Ramsden's; and although Troughton charged a higher price than Ramsden for graduating for the instrument makers, yet his engine was soon in full employment, and he was accustomed to declare, in after years, that, by the care and industry of himself and of his younger brother, he was soon as well remunerated by the trade as Ramsden had been by public rewards. About 1788 Mr. John Stancliffe completed his dividing engine; he had been apprenticed to Hindley, of York, and was for many years foreman to Ramsden, whom he is said to have greatly assisted in the construction of his engine. Stancliffe had been chiefly occupied in the graduation of sextants, which, after leaving his hands, were long and deservedly esteemed. After this, Ramsden's engine was copied many times. Troughton continued during many years to practise graduation with success; and he was worthily succeeded by his younger brother, Edward, who was destined to shed lustre on his profession. He conceived and realized an improved method of graduation, which, after having tested by several years of practice, he at length submitted to the Royal Society of London, and was rewarded by that distinguished body with the Copley medal. His memoir, which is inserted in the Philosophical Transactions for 1809, will be noticed more fully hereafter; but we may here quote his own account of the circumstances which first led him to become dissatisfied with the old methods of graduation. He says: "With as steady a hand and as good an eye as young men generally have, I was much disappointed at finding that, after having made two points, neat and small to my liking, I could not bisect the distance between them without enlarging, displacing, or deforming them with the points of the compasses. This circumstance gave me an early dislike to the tools then in use, and occasioned me the more uneasiness, as I foresaw that it was an evil which no practice, care, nor habit could entirely cure; beam-compasses, spring-dividers, and a scale of equal parts, in short, appeared to me little better than so many sources of mischief. . . . . Of the different branches of our art, that of turning alone seemed to me to border on perfection. It occurred to me, that if I could by any means apply the principle of turning to the art of dividing instruments, the tools liable to objection might be dispensed with. The means of doing this was first suggested by seeing the action of the perambulator, or measuring-wheel; the surface of the earth presenting itself as the edge of the instrument to be divided, and the wheel of the perambulator as a narrow roller acting on that edge; and hence arose an idea that some easy contrivance might be devised for marking off the revolutions and parts of the roller upon the instrument."

While Edward Troughton was occupying the attention of the Royal Society with his method of graduation, the Hon. Henry Cavendish also submitted a new method of using the beam-compasses, with a view of avoiding the difficulty of pointing the exact middle of a small space between the two scratches, and of using that point again without altering its conical figure. About the same time, Professor Lax, of Cambridge, communicated to the Royal Society a paper on the art of graduation, which, however, greatly resembled the Duc de Chaulnes' method of dividing a circle. In 1810 Mr. James Allan, a workman, received the gold medal of the Society of Arts for a new, and what he terms a "self-correcting" method of equalizing the teeth on the edge of the engine-plate used for dividing sextants. About the year 1830 Mr. Andrew Ross was rewarded by the Society of Arts for an improved method of dividing, and also for a new circular dividing-engine. In 1843 Mr. Simms, of the firm of Troughton and Simms, applied self-acting apparatus to Edward Troughton's circular dividing-engine.

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[1] Ramsden also invented a machine for dividing straight lines, in which he [illegible] a screw as his original. The value of this machine is not equal to the former, since a long screw cannot be made so accurate as a scale divided by bisection. Mr. Bryan Donkin has contrived a machine in which a screw is the scale, but its errors are corrected by other mechanism. By means of this machine scales have been divided and screws cut with great accuracy. A short account of this machine is given in the second volume of Holtzapffel's "Mechanical Manipulation." We shall have to notice it in the Article SCREW.

Dividing engines have been constructed by Reichenbach, and others, in Germany, and by Gambey, Froment, and others, in France.

Much of the German division is excellent, and of late years Froment's division has excited great admiration. His method is not known in this country, but we believe it is done by a self-acting engine, which is moved by the electro-magnetic machine described at p. 577 of this volume.

The art of graduation is commonly divided into three sections, viz.: 1. COMMON GRADUATION; 2. ENGINE GRADUATION; 3. ORIGINAL GRADUATION.

1. *Common graduation* is the method of taking copies from a pattern which has been already laid down by original graduation; but, as generally practised, it consists of taking copies of a copy. It also includes those cases of original graduation where the usual patterns do not apply, and where the utmost possible degree of accuracy is not required.

The apparatus used with certain tools for common graduation, consists of a *dividing-plate*, which is either a complete disc, or a broad rim connected with the centre by radial arms, and made inflexible by circular rings or edge bars beneath. It may vary from 14 to 30 inches in diameter. The extreme border is divided into degrees and quarters, and just within this is another circle, divided into degrees and thirds. Within are usually engraved such numbers as are required for the dial of the perambulator; Gunter's line of numbers arranged in a circle, and other logarithmic lines. Also tangents in hundredth parts of the radius, and the difference of the hypothenuse and base as applied to the theodolite; also the equation of time for dialling, the points of the compass, &c. In the centre of the plate is a circular hole, made truly perpendicular to the surface, into which is nicely fitted a pin or arbor, which also fits the centre hole in the circle or arc to be divided, and is the principal connexion between it and the dividing-plate while the work is being done. In Fig. 1098 the dividing-plate is shown with a compass ring attached, in process of graduation; this ring is prevented from turning round by means of a couple of holdfasts, two being used, since it is necessary to remove one of them when its position obstructs the work. An index of tempered steel, with a very straight edge, is attached at one end A to a plate of brass, furnished with an angular notch exactly in a line with the straight edge, which notch receiving the arbor of the plate directs the straight edge to the centre. The length of the index is equal to the radius of the plate. At, and below the exterior end, is fixed a secondary index B, reaching as far inward as the lines of the plate extend, its edge being also directed to the centre, but usually placed a little to the right of the other edge, as in the figure. By an arrangement of nuts and screws, the distance of the two parts can be adjusted according to the thickness of the work, so that the secondary index may be flat upon the work. For instruments which are required to be divided on feather edges, such as protractors, a flexible index is sometimes used, so that the pressure of the hand may bring it in contact with the inclining plane; but a secondary index is preferable, if it allow of its position being adjusted to the plane which is to receive the divisions.

The dividing-knife, Fig. 1099, consists of a blade of good steel and a handle of beech-wood. The cutting edge should be quite straight, in a line with the handle, and of the same thickness as the intended divisions. The edge must not be sharp, but rounding, so as to present to the surface which is to be divided a small semicircle, whose radius is equal to half the breadth of the line which it is to make. The back of the blade is about $\frac{1}{15}$ inch thick. The left side should be flat, but

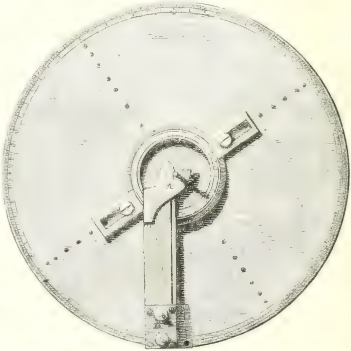

Fig. 1098. DIVIDING PLATE, WITH A COMPASS RING IN PROCESS OF GRADUATION.

the opposite side chamfered in a faint curve from back to edge. The extreme end of the blade makes with

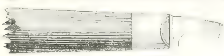

Fig. 1099.

the line of the edge an angle of about 70°. A small chamfer on the side to the right, broad at the back, but vanishing at the edge, reduces the end to an equal thickness. A semicircular recess is made in the edge of the blade near the handle, which affords a relief when the tool is sharpened, and is useful for receiving the inner side of the end of the middle finger. For the further accommodation of the finger, a part of the ferrule of the handle is cut away, as shown in the figure. The curved back of the blade enables the operator to see his work better. The knife is held very much like a pen, but the handle must be quite loose between the thumb and fore finger, which, being placed upon the ferrule directly over the back, is, by its pressure, the chief agent in giving depth to the divisions, the thumb and middle finger acting as supporters, while the other two fingers, as in writing, prop the hand. The knife is held at an angle of about 45° with the plane to be divided, and is used with the flat side in contact with the index of the dividing-plate. The action of this knife is the reverse of the graver, which is *pushed* outwards, and cuts away a fibre in the line of its course, leaving the rest of the metal undisturbed; whereas the knife is *drawn* inwards, and without producing chips, cuts a furrow, while the metal displaced rises in a bur on each side, which is afterwards removed by rubbing with willow charcoal and water.

Before making the divisions, the circular lines, which limit the length of the strokes, are marked out by means of a beam-compass, and made of sufficient breadth and depth by the dividing-knife. The compass ring to be graduated is attached to the dividing-plate, its zero, or north point, being placed so that the index when set to it may also agree with the zero of the plate. The operator then drops the point of the dividing-knife into the line on the plate, and pressing the index to prevent its moving, cuts the corresponding stroke upon the ring. The index is now drawn forwards something more than the value of a division, and the knife being fixed in a second line, it is then pushed back into contact with it, and a second stroke cut as before. In this way he proceeds from right to left until the circle is completed. In dividing upon metals this work is laborious for the hands, and there must be frequent intervals of rest, during which the work is examined with a lens. In dividing upon ivory and wood, the work is so light that an operator will keep pace with a skilful seamstress, a division for a stitch, for any length of time.

Common dividing, as applied to straight lines, is similar to circular dividing. The pattern, of course, is straight, and the scale on which the copy is to be laid is placed beside it; instead of the index above described, the lines are ruled with what is called a *dividing square*; this consists of a straight-edge made of thin tempered steel, with a shoulder at right angles, like a carpenter's square. It is made to slide along the original, stopping at each division, when a corresponding stroke is cut by the dividing knife on the copy.

When box, or other wood, has been divided upon, the bur is first well rubbed off the divisions, and the whole surface polished with a dry rush; the surface is next burnished by rubbing it hard both ways, in the direction of the grain of the wood, with a clean piece of old hat, whereby an agreeable gloss is produced. The divisions are blackened by a mixture of powdered charcoal and linseed oil, laid on quickly, rubbed hard, and cleaned away. This finishes the process. In ivory the divisions are first filled in with a composition of lamp-black and hard tallow, or bees'-wax and olive oil; when this has been hard rubbed into the strokes, the whole surface is well rushed, and then polished with chalk and water, laid upon a linen rag. In finishing brass, after the bur has been taken off with charcoal and water, the surface should be finished off with wet blue stone, which is a very soft slate. Divided gold and silver are best finished with charcoal; but all the metals are improved by being rubbed with the hand after a little oil has been applied.

The *beam-compasses* consist of a beam, A A, Fig. 1100, of any length required, generally made of well-seasoned mahogany. Upon its face is inlaid throughout its length a slip of holly or box, *a a*, upon which are engraved the divisions or scale. Two brass boxes, B C, are adapted to the beam, of which boxes the latter may be moved by sliding to any part of its length, and is fixed in position by tightening the clamp screw D. The two points G H are attached to the boxes, and these may be made to have any extent of opening by sliding the box C along the beam, the other box, B, being firmly fixed at one extremity. The nice adjustment of the points G H is attained by means of the two verniers[1] *b c*, fixed at the side of an opening in the brass boxes to which they are attached, and afford the means of minutely subdividing the principal divisions *a a* on the beam, which appear through these openings. E is a clamp screw for a similar purpose to the screw D, viz. to fix the box B, and prevent motion in its point after adjustment to position. F is a slow motion screw, by which the point G may be moved a minute quantity for perfecting the setting of the instrument after having been set as nearly as possible by hand alone.

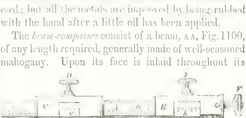

Fig. 1100. BEAM COMPASSES.

For some descriptions of dividing, the compasses

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(1) The principle of the Vernier is explained in Article BAROMETER, page 103.

called *spring dividers*, Fig. 1101, are useful. They consist of a circular steel bow and two legs, all in one piece: the bow allows a motion of the points from the distance of about an inch, or 2 inches, to their contact. The points may be brought near together by means of an adjusting screw attached to one of the legs by a pin passing through it, and upon which it turns as in a centre, the elasticity of the spring exerting a pressure against the screw, (or rather against a sharp angle attached to the screw,) and thus keeping the points at the distance to which they are set. The legs are bored to receive the cylinders or points, which are ground to the requisite fineness and brought very near the inner extremity of the diameter in order to measure the shortest possible distance; but at the point they are made round, and in every direction the sides must make equal angles with the perpendicular, otherwise a distance set off with them would be altered by pressure. In using this instrument the forefinger is pressed upon the bow, the thumb and middle finger keeping it upright, while the other fingers prop the hand; but where a distance is to be set off many times in succession, the dividers are to be twirled round in the same direction, making a dot at every half turn. For accurate bisection of a distance, the instrument must be held by the leg near the point, which is lodged in one extremity, while with the other a faint arc is described; the same thing being done from the other end of the distance, the middle point is secured by making a dot with a fine conical pointril. In using the dividers a magnifying glass held in the left hand must always be employed.

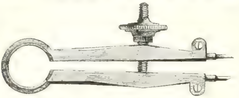

Fig. 1101. SPRING-DIVIDERS.

In dividing a common thermometer, several points, 12 or 15 degrees apart, are marked off in accordance with a standard instrument; these, which are always unequal, are filled up with equal parts. Suppose the distance from one mark to the next is 15°; instead of first dividing the space into 3 or 5, the operator guesses, or estimates the distance of 1°, and running the divider over the space almost as quickly as he can count its steps, he ascertains how much he has erred; a second or third trial is sure to give him the proper distance. The dots in these trials, two of which should never be in the same line, are scarcely to be recognised by the lens, and he requires the last set only, so that by repeating the steps with greater pressure he may make the dots sufficiently large to receive the point of the dividing knife.

2. *Engine graduation.*—Ramsden's engine has formed the basis of the subsequent improved instruments, which we are about to describe; it will not therefore be necessary to give more than a general idea of its principle, which is as follows:—A horizontal circle 4 feet in diameter is made to turn upon a vertical axis: the outer edge of this circle is *ratched* or notched by an endless screw, one revolution of which carries the circle round 10′: the pressure of the foot upon a treadle turns the screw forward, and by a series of ingenious contrivances the operator can turn the screw through any portion of its revolution at each descent of the treadle, and the position of the parts is restored when the foot is taken off, without allowing any return motion to the screw. The circle to be divided is fixed upon the dividing engine, and made concentric with it, and a division is cut after each pressure of the foot.

Mr. Edward Troughton's dividing engine, which was completed in 1793, will be understood from the following figures and description.[1] Fig. 1102 is a plan, and Fig. 1103 an elevation of the engine. It is mounted upon a strong frame of wood, the upper part of which serves as a box to preserve it, and which at certain places opens for use. This stand serves to support the machine at a convenient height, and the only portion of it represented in the figures is the platform E E. The lowest part of the engine is a heavy tripod of cast brass; two of its branches are denoted by A A in the plan: the third is covered by the work above. In Fig. 1103, the tripod is also represented by A A, below which are three finger screws B B, that support it on the platform and serve the purpose of levelling the engine. They work in the tripod with their heads downwards, and are placed in the broad part where the two branches meet. At about 2 inches from the centre of the tripod, and at equal distances from each other, are 3 conical tubes C C, extending downwards nearly 3 feet; the third is concealed behind the axis of the engine plate. They are connected at the lower ends by a strong piece of brass F, which, together with the centre of the tripod, forms a frame wherein the axis revolves. The engine-plate G was cast in one piece, except the circular limb. The form of the 12 radii is seen in Fig. 1103; they are connected by a central part, equal in thickness to their greatest depth; but the broad circular centre piece, as well as the circular ring, are not thicker than the limb. The latter is 3 inches broad and ½ inch thick, and is formed of one piece of fine plate brass without soldering. It is rabbeted upon the extremities of the radii, so as to bring its upper surface into the same plane with them, and made permanently fast with rivets. The axis of the plate D is a strong conical tube 4 inches in diameter at the upper end, and half as much below. Its length is determined by the 3 cones of the tripod. At the upper end it is firmly fixed to the centre of the plate; the lower end terminates in an obtuse point of steel. At the upper end of the axis, a steel arbor was passed through the plate from below, 2 inches above its surface: upon these 2 points when revolving in

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(1) Mr. Ed. Troughton described his own engine in the *Edinburgh Cyclopædia*, article GRADUATION, from which our description is abridged. We are also indebted to this article for much valuable information in the other sections of this notice.

the lathe, the surface of the plate was generated and its outer edge made perfectly circular. The teeth in the limb were cut by a screw having 20 threads in an inch, and as it was intended that by one of its revolutions it should carry the plate through an angle of 10′, it followed that the circumference of the plate should be 108 inches. From the measure of the screw, therefore, the dimension of the exterior border of the plate was derived first by computation nearly, and afterwards by trial with the screw itself.

A strong collar of bell-metal had been soldered upon the axis and made concentric with it when the limb was turned, the position of this collar coinciding in height with the body of the tripod. The centre of the tripod is hollow, to allow the collar to pass through, but does not form a socket for it to work in. Instead of that, two narrow pieces of steel are fixed vertically at an angle of 120° with each other. Against these the collar is pressed by a steel spring planted at 120° distance from them. In this triangular bearing the axis is supported at top, while the piece F receives the point at the lower end, and supports the whole weight. To the front branch of the tripod is screwed a strong plate of brass, as shown in the plan, extending inwards half-way to the centre and outwards somewhat beyond the border of the wheel. Its breadth is rather more than the length of the screw arbor. Above this and in contact with it, is a similar plate, to the under side of which are screwed 3 oblong pieces, the thickness of which is equal to that of the lower plate. One of these at the middle of the inner end of the plate, and the other two at the outer end near the edges, are received by slits cut in the lower plate, and which are about $\frac{1}{8}$ in. longer than the pieces, and allow a motion of the upper plate in the direction of the radius, equal to that quantity, but afford it no lateral play. The dividing screw is fastened to the upper plate, and partakes of its motion, in order that, when required, the threads of the screw may be disengaged from the teeth of the limb. Two pieces H, connecting the screw with the upper plate, extend towards the centre as far as the plate, and form edge bars to strengthen it. In Fig. 1105 the shape of these pieces is best shown, and the mode in which they are brought from below for placing the screw even with the edge of the wheel, and also how the screw arbor is centered in them. The arbor of the screw is cylindrical, and a portion of each end forms a cylinder of smaller diameter. The shoulders which near each end of the arbor limit these parts, prevent lateral play in the pieces last described; for the smaller parts work freely in the holes of those pieces, the shoulders being in contact with their inner edges.

The engine was now ready to receive the original graduation of its limb, and this was done according to the principle explained in the third section. It may, however, contribute to the completeness of this part of our subject to select a few particulars from Mr. E. Troughton's account of the actual process on the engine under description. In the first place, a roller was placed horizontally in a frame attached to the tripod so as to have free and steady motion round its own axis; and was so adjusted as to be carried exactly 16 times round while the engine-plate made one revolution. This roller was itself, near the edge upon its upper surface, divided into 16 parts. Upon turning the plate round, these 16 divisions 16 times told = 256, came in succession to the wire of a fixed microscope, and were by a proper apparatus transferred to the surface of the plate, in fine dots, at a sufficient distance within the edge to prevent their being disturbed by making the teeth. To accomplish the next step an index was made to revolve upon the arbor of the plate; it was composed of two branches equal in length to the radius of the circle of dots, each of which carried at its extremity a microscope with a micrometer: these had a range of angular motion respecting each other from a right line to a very small angle. By this index and these microscopes the 256 fine dots were examined by a certain bisectional process, from which their individual errors were investigated by computation and formed into a table. By the help of the table of errors, the future work of racking the limb was prosecuted with as much certainty as could have been done had the original divisions been inserted without error. As the value of a tooth of the limb was to be 10′, the whole number of teeth would be 2,160; now $\frac{2160}{256}=8\frac{7}{16}$; and just so many revolutions and parts of the dividing screw will be commensurate with a mean space from dot to dot = an angle of $1^\circ\ 24'\ 22''.5$. In order, therefore, that a comparison between the plate and the screw might be made at every original dot, it was necessary to provide means for ascertaining the position of the former at every 16th part of a revolution. To this end a micrometer head, as large as could be admitted, divided into 16 equal parts, was fixed upon the left end of the screw arbor, and contiguous to this was placed a fixed index bearing a fiducial line. Now, as it was impossible to lay down these 256 dots without some errors, it was necessary next to determine their true places from their apparent ones. A lower subdivision of the micrometer head, therefore, became necessary, and each of the 16 spaces was divided into 10 by actual division.

The 256 dots having been transferred to the plate, the roller was removed, as also the double index and microscopes from the central arbor, when the position of those dots had been ascertained. The dividing screw was now placed in its frame; and a micrometer with a movable wire fixed to the tripod for viewing the primitive dots, and a winch for turning the screw attached to its arbor on the right; this change of parts being effected, the screw with its frame having free motion in the line of radius, and capable of being, by the force of a spring, pressed into contact with the edge of the plate, or by a screw drawn backwards at pleasure: the plate itself having free motion round its axis, the important operation of forming the teeth or racking the circle was commenced.

In order to prevent mistakes by beginning an interval at a wrong 16th of the head, which by making false marks would occasion much trouble, those parts were numbered 1, 2, 3 . . . 16 in the order of turning the screw forwards. Corresponding numbers were marked in ink upon the plate opposite to the dots, the order of which, from right to left, was 0, 7, 14, 5, 12, 3, 10, 1, 8, 15, 6, 13, 4, 11, 2, 9, which, repeated 16 times, completed the circle. This allowed the work to be done with confidence, for, in beginning any interval, it was only required that the number upon the head should be that which distinguished the dot under the wire of the microscope. In the table of errors those dots which were too forward were marked with the sign —, and those that were too backward +, since a + position of the screw will effect a correction of a — error of the dot, and the contrary. The *zero*, or first dot, being without error, is, by turning the plate round, to be brought exactly under the wire of the microscope, and the division of the head marked 0 made to coincide exactly with the fiducial line. The spring is now allowed to press up the screw into contact with the edge of the plate, and then, by means of the winch, the screw is to be turned through $8\frac{7}{16}$ revolutions, which will make impressions upon the edge of the plate and bring up another dot to the wire of the microscope. The screw must now be released, and the plate turned backwards so as to bring that dot to the wire which precedes the one that the former interval began from, which dot is marked 9, and the division of the head marked 9 must be brought to the fiducial line, but not exactly; for in this, as well as in every future interval, the tabular error of the dot must be allowed for according to the subdivisions of the head; the screw being again pressed up and turned with the winch, this interval will also be indented. In thus proceeding in a retrograde course from one interval to another, until the whole circle has been gone over, a slight impression of the screw is made at each of the 2,160 revolutions. The marks thus made are laid on, as it were, in patches, the beginnings of which are agreeable to the original corrected dots, but at every other point they are subject to the error of mismeasurement of the screw as well as to that of its irregular action. The backward process in making the first impression was to prevent accumulation of errors, which must have arisen had the screw been turned forwards through successive intervals; but as the impressions already made were sufficiently deep for the screw in its future action to follow them, and by its own equalizing action to produce agreement between the beginning of one interval and the end of another, it was necessary to pursue that process. Thus far the threads of the screw had not been made to cut, but merely to indent the edge, the metal on each side of every indentation rising in a bur; but 4 or 5 of the middle threads had already been worn into action. In order to rack from these slight indentations to the full tooth, it was necessary that the screw should cut like a saw; for which purpose the spiral notches, which in opposite directions are shown in the figures crossing the threads of the screw, were made with a sharp-edged file, and in order to preserve sharpness through long-continued action, these notches were, from time to time, filed deeper and broader. The operation was a tedious one, and occupied nearly a month. The chief difficulty arose from the circumstance, that the threads of the notched screw cut sharper with one edge than with the other, and consequently the indentations gained or lost upon the original divisions. By frequently sharpening the screw opposite various parts of the limb, the error arising from this source was sometimes +, and sometimes —, and that to the amount of 7″ or 8″ in some parts of the circle. These errors were corrected from time to time, as they were found to exist, by pressing the wheel forwards or backwards, so as to force the screw in its revolution to remove more metal on one side of the indentation than on the other. This Mr. Troughton thinks a sufficient answer to those who would propose a self-correcting method of racking an engine. In former engines the notches of the screw were cut parallel to the axis, which caused an irregular jerking motion in consequence of the whole length of each cut coming into action at once, thereby cutting up the screw, and rendering a duplicate necessary. In the present engine this inconvenience was avoided by making the notches in spirals which, crossing each other at equal angles, gave in one set the preceding edge, and in the other the following edge, the most advantageous cutting angle. Besides this, a revolving pressure was sufficient to cause the notches to rake off every impurity from the teeth of the wheel and keep them perfectly clean.

We now return from this long description of one of the most delicate and difficult of mechanical operations, to complete the description of the engine. Fig. 1106 shows, in perspective, the apparatus for carrying the wheel forwards by the screw, the connexion between the screw and the foot, and the method of stopping at every division. The chief parts of this apparatus are shown in all the figures; but the method of supporting it on the platform of the stand, by the block I, is seen only in Fig. 1103. The principal piece is a cock, J, the horizontal part of which has two branches, one shown in the figure, between which the strings pass to the T treadle, Fig. 1103. The vertical part supports a steel cylinder, which, when the screw is in action, forms a right line with its arbor; but there is left between their ends a space of about half an inch: this affords means for changing the ratchet wheels which are placed upon the screw arbor, and move round or stop with it. A barrel, about 2 inches long and $1\frac{1}{4}$ diameter, is fitted upon the cylinder, but so as to be turned round and moved upon it with perfect freedom from end to end. The middle part of the barrel is formed into a spiral worm, or screw, the groove of which receives a cord or cat-gut of $\frac{1}{10}$ inch in diameter. There is a slight frame dove-tailed upon the horizontal branches of the cock, shown in front of Fig. 1104, which has steady and free motion in the direction of the cylinder; to each side of this frame is attached a pallet, one of which enters in front, and the other behind, into the spiral of the barrel, by which means,

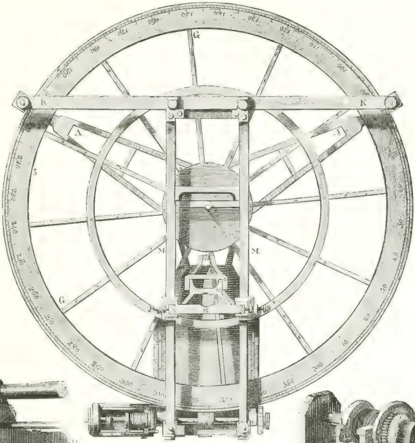

Fig. 1102 PLAN.

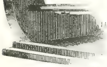

Fig. 1105.

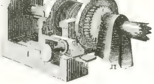

Fig. 1104

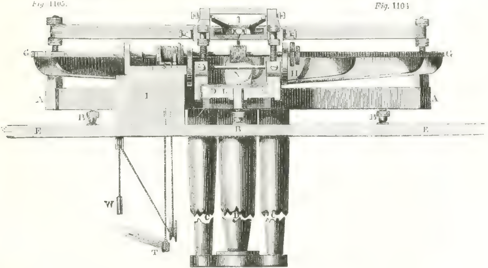

Fig. 1103 ELEVATION OF TROUGHTON'S DIVIDING ENGINE.

when the latter is turned round, rectilinear motion is given to the frame. The barrel to the right is large and excavated, so as to admit the ratchet-wheel, which latter is driven by a catch and spring planted in the edge of the cavity in the former. The end of the barrel to the left is embraced by a ring, which is capable of being turned round or set fast at pleasure. A stopping-piece is fastened to the frame by a finger-screw, and by means of a slit, through which the screw passes from the ring of the barrel, varied through a considerable extent. The elevated part of the stopping-piece resembles an anvil, and the hither side of the ring of the barrel, a hammer: the contact of these determines the point from which divisions begin: each division is terminated by similar means: an anvil is found in the elevated part of the frame behind, and a hammer in a screw-head projecting from the enlarged end of the barrel: a string, occupying 4 or 5 turns of the groove of the barrel, is attached at one end to a treadle near the floor, and at the other, after passing over two pulleys, to a weight behind. When the treadle is pressed down with the foot, the hammer in front is lifted off its anvil; and as the barrel is carried round, the frame is moved forwards by the pallets, so that in the second turn they pass clear of each other, and the motion is continued until the anvil behind is struck by the other hammer: during this time the catch, by the pressure of its spring, has hold of the perpendicular side of a tooth of the ratchet wheel, carries the screw round along with it, and moves also the engine-plate through the proper angle. On gradually withdrawing the pressure of the foot from the treadle so as to let the weight prevail, the barrel will be brought round in a contrary direction: the hammer and anvil on the further side leave and pass each other, and then those on this side pass and meet as at first, ready for a second tread. During the time that the barrel runs backwards the screw and engine-plate stand still; for the sloping sides of the ratchet-wheel allow the catch to escape freely over them. According to the arrangement in Fig. 1104, a tread gives only 2 revolutions of the screw, but the number may be varied at pleasure as far as 6; for let the anvil in front be placed by its finger-screw so much to the right as will allow the hammer to escape it, the weight will then draw the barrel back through another revolution and the parts will meet again. Parts of a revolution are obtained with equal ease. As the ring of the barrel, to which is attached the hammer in front, may be turned round and fixed at pleasure, it is evident that if the hammer were brought down so as to meet the anvil sooner, the tread would be shortened; and if shifted the contrary way it would be lengthened. Thus, by changing the position of the anvil, the number of complete revolutions can be varied; and as parts of a revolution are obtained by shifting the hammer, the angular value of a tread may be varied from 6 revolutions of the screw down to a single tooth of the ratchet-wheel. The most useful number for the teeth in this wheel is 120, for it answers to the division of the vernier that gives 5″ of the usual degree, or 10″ in instruments of reflexion, as well as to many others. For other purposes ratchet-wheels, of 80, 100, &c. teeth, may be substituted.

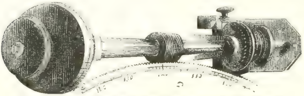

Fig. 1106. PART OF ENGINE PLATE, WITH THE MILLED HEAD AND DIVIDED MICROMETER.

On the end of the screw-arbor to the left, Fig. 1106, is attached a milled head and divided micrometer; the latter, like the ratchet-wheel, changeable at pleasure, and carrying the same number of divisions that the wheel does teeth; the micrometer turns round with the screw, and a cock fixed to the frame, bearing a fiducial line, serves as an index for counting the divisions. By the help of this the stopping apparatus can be set to any part of the revolution of a screw without the trouble of a second trial; and by it, in case of a false tread, or other accident, the parts can be again adjusted.

The frame and apparatus for cutting the divisions, and their connexion with the engine, have now to be described. Upon the two remote branches of the tripod, and beyond the border of the wheel, are erected 2 pillars, the upper parts of which are formed into screws. Four screw-nuts work, two and two, upon the screw part of these pillars, and, embracing the ends of a strong brass bar, K K, which they support, allow the height to be adjusted so as to suit the thickness of the work to be divided. To the near branch of the tripod a cross-piece, L, Fig. 1103, nearly the length of the screw-arbor and parallel to it, is firmly fastened. This carries upon its extremities 2 pillars similar to, but smaller than the others. Upon the strong bar, K K, at equal distances from the middle, are roller-bars fixed by finger-screws. They extend from the strong bar to the pillars in front, to which they are secured by double-nuts like the former. These 2 bars, M M, Fig. 1102, are bound together by a cross-brace at the remote end, and by another a little way beyond the centre. In no other part can crossing-pieces be allowed; for as they form the support for the apparatus that cuts the divisions, uninterrupted motion along the whole line of the radius is required.

The cutting apparatus consists of 3 principal pieces, *a*, *e*, *o*, Fig. 1102. The first is a bridge which crosses the space between the bars, M, M, and to which it is attached at the ends by sliding sockets: these run along the bars, and can be clamped thereto at any part so as to suit the length of the radius of the instrument which is to be graduated. Two steel screws, with conical points, are tapped through the perpendicular ends of the bridges above the sockets, and by working in holes of the second piece, form an axis or joint round which the latter has a free and steady motion. The third piece, the form of which, as well as of the second, is seen in the plan, has also steel screws with conical points tapped through its ends, and these, like the others, act in the middle piece, forming another horizontal axis parallel to the former, and in every respect like it. In Fig. 1102, the parts are extended, for the purpose of being better shown, into a position in which they cannot work. The best effect is produced when the middle piece is vertical, and the third horizontal. Sufficient freedom of action is found in this contrivance of Hindley's to produce a rectilinear motion of the pointril of at least one-third of an inch, a quantity fully sufficient for the required purposes. The part of the third piece next the centre, is that in which the pointril is placed. It is so contrived that its length below the piece may be varied at pleasure; that it may be turned round upon a horizontal axis so as to make any angle with the plane to be divided upon, and that its action may be viewed by a properly-attached magnifying-glass.

In Fig. 1103, a bar, attached to the same pieces that support the screw-arbor, to which it is parallel, and placed below it, together with a cock behind, bear the axis of a vertical friction-wheel, x. The wheel is placed so as to roll in contact with the under side of the limb of the engine immediately below the dividing screw. Without this the action of the screw in the teeth of the wheel would occasionally produce a harsh jarring sound, but it is rendered mute by this contrivance.

A hardened and tempered steel arbor rises full 2 inches above the surface of the plate in the axis of which it is immovably fixed. In the other engines the axis is hollow, so as to admit arbors of different size to suit the centre holes of the instruments to be graduated; but as Mr. Troughton, in using this engine, divided only his own instruments, he made them, whether large or small, so as to suit his arbor, and thus avoided one source of uncertainty and error. This arbor is the principal connexion between the engine and the work to be graduated, and requires the most exact fitting. Tapped holes, variously arranged through the length of the 12 radii, furnish the means of applying holdfasts to prevent accidental circular derangement.

With this engine the operator can cut 24 strokes in a minute of time for hours together.

The history of machinery during the last half century elicits the remarkable fact, so illustrative of a very high state of civilization, that most of our machines have had impressed upon them the character of self-acting engines. Nothing shows more strikingly the supremacy of intellect than an arrangement of brute matter capable of performing mental operations with unerring precision. The analytical engine, by Mr. Babbage, and the self-acting spinning-mule, belong to this class; to which we may also add Mr. Simms's self-acting circular dividing-engine.

Although Troughton's engine, just described, was a great improvement on its predecessors, yet it required the constant attention of a skilful operator, at a great sacrifice both of time and of health, the effect of which was to add considerably to the cost of the instrument. Mr. Simms (of the firm of Troughton and Simms) therefore determined so to arrange the engine as to bring it under the yoke of some external moving power, such as a descending weight, a steam-engine, or a boy turning a winch, and having performed its work of dividing an instrument, to throw itself out of gear. The accompanying steel engraving represents an elevation of this engine, showing the apparatus for moving the engine-plate, and for cutting the divisions, together with the manner in which their operations are connected; and the following description will show in what respects it differs from E. Troughton's engine just described in detail.[1]

The circle or engine plate is of gun-metal, 46 inches in diameter, and was cast in one entire piece by Messrs. Maudslay and Field. The centre of the plate is also peculiar; it being so arranged that it can be entered by the axis of the instrument to be divided, and the work thus brought down to bear upon the surface of the engine-plate. In former cases it was necessary, either to divide the instrument *originally*, which on account of the expense was seldom done; or to separate the part intended to receive the divisions from its axis and contiguous parts, in which state alone could it be placed upon the engine. The danger of detaching the instrument from its centre and framing is, that when reframed there is frequently a sensible excentricity; that is, the centre of the divided circle is not in the axis of rotation. This, however, does not lead to error, if two or more opposite readings be read. The great danger is distortion of the circle when the instrument is again put together. When the divided limb is only part of a circle, as in the sextant, any error of excentricity may become sensible, notwithstanding the care of the artist. In the present engine these difficulties are obviated, as already stated, by not dismounting the instrument.

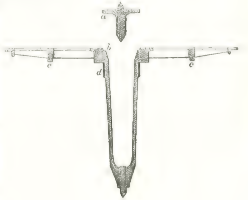

Fig. 1107.

Fig. 1107 is a section of the engine-plate and centre. In order that it may serve for all cases, the plate *a* is truly fitted into the recess *b*, and its upper plane made to coincide exactly with the general surface of the plate. Steel arbors of various sizes, one of which is shown in the figure, are adapted to this central plate. Friction rollers bear against the projecting-ring *c*, which has a groove turned on the edge, around which a cord may be coiled, to overcome by a weight the inertia of the machine: but this has proved unnecessary. The centre terminates in a steel point, and turns in a collar of steel *d*, fitted into the centre of a massive tripod by which the machine is supported.

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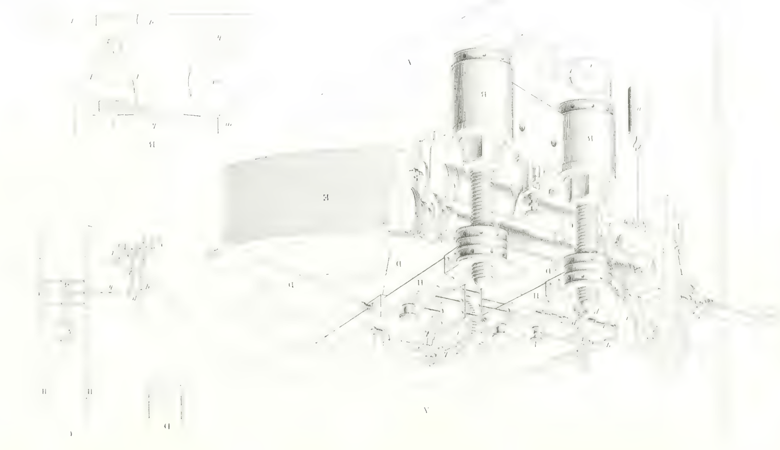
[1] The description of Mr. Simms's Engine is contained in the Memoirs of the Royal Astronomical Society, vol. xv. 1846.

On the surface, and not far from the edge of the engine-plate, are two sets of divisions to spaces of 5 minutes; one upon a ring of silver, with fine lines for microscopic purposes, and the other upon the gun-metal face, cut strongly, so as to be easily seen without the assistance of a lens. There are also as many teeth upon the edge as there are divisions upon the face of the engine-plate, viz. 4,320; so that one revolution of the endless screw moves the circle through a space of 5 minutes. The circle was divided with extreme care; the first computation of the errors of the original points being merely made use of for the insertion of a second series of points, the errors of which, although exceedingly minute, were measured, computed, and tabulated in like manner; and from this second series the divisions were cut. The edge was ratched with a single circular cutter mounted in the endless screw-frame, and as each division in order was brought to coincide with the wires of a powerful microscope, the cutter was entered, and 3 circulations of the engine-plate completed the work.

The cutting apparatus is shown at B in the steel engraving, partly in section, and separated from its supports and other parts which conceal it in the engine: *e* and *f* are the two members of the cutting-frame (which is similar to Hindley's as described in Troughton's engine), but the tail of *f* is prolonged in order to carry the counterpoise *g*, by which the pressure of the point upon the work, and consequently the depth and width of the divisions, are determined, and also that the revolving excentric *h* may alternately lift the point from the work and allow it to descend upon it to cut the division: *i* is a plate with an undulating edge, by which the alternations of long and short strokes are regulated. This requires to be changed from time to time according to the nature of the work; the one represented is made use of in division to spaces of 5′, where the third and sixth lines have not only to be distinguished from the intermediate arcs, but also from each other, by their length. The motion of the plate *i* is communicated to the cutting-frame *f* by means of the bent lever *l l*, one extremity resting on the edge of the plate, and the other pressing against the front of the cutting-frame, contact being maintained by the spring *l*. A pinion upon the axis of *h* acts in a wheel upon the axis of ***i***; and these are so proportioned that *h* makes 6 revolutions to 1 of *i*, a proportion that answers for 5′, 10′, 15′, or 20′, upon the circle under graduation, by varying the plate *i*. Now, supposing a division to have just been cut, and the excentric, by its revolution, to be about to lift the point from the work: this having been done, the end *m* of the bent lever descends the inclined plane, and the cutting point is thereby allowed to return from *n* toward *o*: in due time the motion of the excentric allows the point again to descend upon the work: the lifting of the end *m* of the lever by the next advancing protuberance, and the consequent pressure of the other extremity against the front of the cutting-frame, causes another division to be cut. The respective lengths of the divisions are obviously regulated by the radii of the several projections on the edge of the plate. This cutting apparatus is connected with the endless screw for working the engine-plate by means which are shown in plan in Fig. C, and in perspective in Fig. A, of the steel engraving. In C, *h* represents the axis of the excentric; *p*, a pair of bevelled wheels fitted to a box, which slides along the bar *q*, in order that the cutting point may be adjusted to the required radius, and for the same purpose the bar *r* consists of 2 tubes, sliding within each other, and capable of being fixed at any point by means of an external clamp. Another pair of wheels, at *s*, changes the direction of the motion, which now becomes parallel to the endless or engine-screw, and the shaft to which the last bevelled wheel is attached is turned by the external machinery. Each extremity of the shaft *t r* terminates in a crank: that at the end *t* is connected by the eye, Fig. D, to the cord coiled round the spiral barrel, and thus communicates its motion to the endless screw; the other merely raises a weight, which, in its ascent, checks the accelerating tendency of *t* during the return of the ratchet-wheel, and in its descent acts as an auxiliary in giving motion to the endless-screw, thereby preserving uniformity throughout the whole action, which would otherwise be unequal and interrupted. The spiral barrel and ratchet-wheel are similar to those described in Troughton's engine. The wheels at *p* are drawn in Fig. A, of equal size, in which form they serve for graduation into spaces of 5′, which is the most usual upon work where the subdivision is effected by reading micrometers, and also in many cases where verniers are used. For other spaces these wheels must be proportioned, or the same thing may be effected by increasing the length of the crank.

In the steel engraving all the essential parts are given, which serve for moving the engine-plate, and for cutting the divisions. A is a branch of a strong well-braced stand of wood, upon which the whole machine is placed. B B, the metallic tripod, in the centre of which the engine-plate turns, and to which all the superior parts of the machine are firmly attached. C C, the endless-screw frame, which turns upon finely polished steel pivots. The screw is kept in contact with the edge of the engine-plate with a proper degree of pressure by a spiral spring acting under the lever *w*, and can, when necessary, be discharged from action by the screw opposed to it. D D are portions of the engine-plate, and E represents


R
R
E

a hoop of mahogany by which it is surrounded, and its edge protected from injury. H H are parallel bars, to which the cutting apparatus is fastened. (See also Fig. C.) *p*, *q*, *r*, *s*, and *t*, exhibit, as before, the parts connecting the motion of the cutting-frame with that of the endless-screw; but in the steel engraving, the crank, and its connexion with the cord wound round the spiral barrel, are more clearly shown than in the figure, where they are represented only in plan. The eye (Fig. D) by which this connexion is made, consists of 2 pieces, one to fit upon the crank, and the other to fasten to the cord: these parts are kept together by spiral springs, which by their elasticity prevent the jerk that would otherwise be given at each revolution of the crank. This part is also clearly shown in the steel engraving. *u* is the weight connected with the crank *v*; the opposing weight, or that to which the cord proceeding from the spiral barrel is fastened, is within the framework of the stand: the cord, in its progress towards it, passes over the pulley *x*, and also over another pulley within the stand.

A pair of plates, with serrated edges, is shown at *y*: these plates serve to establish the connexion between the engine within the apartment and the driving machinery without. One of the plates is fastened to the cylinder *z*, which passes through the wall of the apartment, and the other can be thrown in or out of action by the handle I; so that the connexion can be made and broken in a moment.

The method by which the engine can discharge itself from action, when it has completed its work, remains to be noticed. Against the handle, I, a spring is made to exert a pressure, the tendency of which is to detach the engine from the external machinery: this is opposed by a trigger turning on very delicate centres, and carrying a friction-roller at its other extremity. Upon the engine-plate, a small well-polished wedge is fastened, which, as it circulates, passes under the friction-roller, which it lifts, and consequently discharges the bolt at the other extremity. This apparatus of course requires careful adjustment before the operation of dividing commences.

In the year 1831 Mr. Andrew Ross received the Gold Isis Medal and fifty guineas from the Society of Arts for his improved method of dividing instruments, and for his circular dividing-engine. We regret that we cannot, within our limits of space and illustration, do more than give a general idea of the principle of this engine. To do full justice to it would require us to copy the numerous illustrative engravings which accompany Mr. Ross's paper in the 48th volume of the Society's Transactions.

It will be remembered, that in Ramsden's, and also in Troughton's engine, the circle which carried the instrument to be graduated was moved round by the teeth of an endless screw working in corresponding notches cut in the edge of the circle, and the endless screw was made to turn on its axis by a catgut band passing round a spiral in the same axis, and fastened below to a treadle which was worked by the foot. Mr. Ross objects to the serrated cylindrical screw on account of the great pressure required being inconsistent with those delicate operations so necessary to accuracy in such a machine; and he also thinks that variations in density in the steel screw, and porosity and other inequalities in the cast-metal circle, are likely to lead to error. He therefore gets rid of the driving motion of the screw, and obtains a rotary motion by an independent apparatus: he can also stop the circle at its precise angular position by the contact of plane and spherical surfaces of hardened steel. A more steady motion is given to the circle, and it also admits of being so adjusted that the inequalities produced by the wear of the parts may be obviated.

The circle C, Fig. 1108, turns on its centre on a vertical axis, the lower extremity of which rests in a cup at one end of a lever, and a counterpoise being hung at the other end, the axis is thus pressed upwards and diminishes the pressure of the circle on the rectangular cast-iron frame which supports it, a portion of which is shown at A B. Around the circle are screwed 18 projections, *a a*, through which are passed capstan-headed screws parallel to the plane of and tangent to the circle. The ends of the screws are hardened and ground flat and square to the axis, and the screws themselves may be fixed in any position by means of tightening screws. At one end, A, of the rectangular frame, a sliding apparatus carries a cylinder, D, turning on a horizontal axis: on the surface of this cylinder is a worm, or spiral projection, *b b*, which enters between the projections *a a*, and the distance between the two turns of the spiral is rather greater than the breadth of one of the projections, *a*. A number of steel screws pass through the spiral thread; and the ends of these screws are turned in the form of hemispheres, so that after every movement of the circle C, and of the spiral *b b*, the engine is held in a state of rest by the abutment of the hemispherical end of one screw against the flat end of the other. On the outer rim of the circle C, below the projections *a*, is a groove in which an

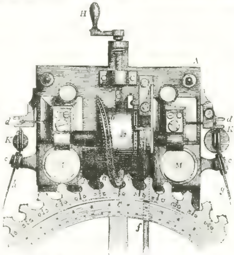


Fig. 1108. MR. A. ROSS'S DIVIDING ENGINE.

endless catgut band, G H, passes round, moving over pulleys; first over *c*, a fixed pulley; then under a movable pulley, from which is suspended a weight, K: it then passes above the machine to a notch at *d* in the direction *d d*. Four pillars, of which M M are two, rising from the frame A B, support a stage which carries the cutting apparatus, and this is so formed with joints as to allow the tool to be moved up or down, or in the direction of a radius of the circle C, but not on either side of that radius: there is also a contrivance for determining the length of the lines of division. By moving one end of a lever at the opposite extremity of the frame A B, a bar, *f f'*, which is attached at one end to that lever, gives motion to a catch or click so as to cause a ratchet-wheel to turn on its axis, and thus give the requisite movement to the cutting tool: the other extremity, *f'*, of the bar, by turning a lever on a horizontal axle containing within it the axle of the cylinder D, allows a catch or click to turn a ratchet-wheel on the latter axle, and, with it, the cylinder itself; and thus a side of the spiral projection, *b b*, is removed a little way from its position when in contact with one side of a projection, *a*. The first lever being moved back again, a spring, which had previously pressed against the catgut band, is drawn off; and thus, one of the weights K, by drawing down the band and pulley above it, gives a small movement to the circle C, and brings the side of a projection, *a*, again in contact with the side of the spiral. According to the place at which the bar *f f'* is applied to the lever on the axle of D, the catch may pass over any required number of the teeth of the ratchet-wheel, and thus the circle C may be turned through any angle consistently with the values of the divisions intended to be cut.

The original divisions on the circle C are made on silver studs let into its surface, and the screws passing through *a a*, *b b* are so adjusted by means of their capstan-heads, that if the end of a screw in *b b* is in contact with the screw in any one of the projections *a*, one complete revolution of the spiral *b b* may bring the end of the screw in the next projection, *a*, in contact with the same screw in the spiral. The corresponding movement in the circle is equivalent to the interval between two of the original graduations; and the movement is verified by the primitive divisions coming successively to a wire in a microscope.

3. *Original graduation.*—We now come to notice, very briefly, the art in its highest order, an art which for ages was carried on in secrecy and silence by men of science as well as by artists. It has been described as one of the nicest operations of manual labour, in which few are qualified to succeed: indeed, the importance of the art may be estimated from the high consideration in which the successful artist is held by those who are qualified to appreciate his labours. The engines described in the last section are mere copying engines, and we believe it is not decided whether circles from the same engine are fac-similes. But the work of original graduation is so arduous, that, as Mr. Simms remarks, "to copy the divisions from a circle of large diameter which had been graduated with extraordinary care, upon work of smaller dimensions, would in general be more satisfactory than original graduation. The latter process consists of several successive steps, in any or all of which a certain amount of error may escape detection. In general, such errors go far to balance one another; but there will be parts in almost every work where faults of graduation appear which can only arise from an accumulation of minute errors."

The earliest methods of dividing of which any detailed account is given, are those by Hooke and Römer. Hooke's method consisted in racking the edge of his quadrant with an endless screw, and to use the revolutions and parts of the screw as a division; but this method was found in practice to be very defective unless checked and corrected by independent divisions. Römer's method was *stepping* a fixed distance throughout the whole of his arc, the distance being so proportioned to the radius of the arc, that it was very nearly equal to one of the smaller divisions required, the total length of the arc being in this case disregarded, as any number of divisions were converted into degrees and minutes by a table calculated for the purpose.

Hindley's method was nothing more than an original, highly ingenious method of stepping. It is described in the following letter which he addressed to Smeaton on the 14th of November, 1748; and the reason why it was not published until 1786 was, that Hindley entrusted it as a secret to Smeaton. He says:—"First choose the largest number you want, and then choose a long plate of thin brass: mine was about 1 inch in breadth and 8 feet in length, which I bent like a hoop for a hogshead, and soldered the ends together, and turned it of equal thickness upon a block of smooth-grained wood, upon my great lathe, in the air, (that is, upon the end of the mandrel): one side of the hoop must be rather wider than the other, that it may fit the better to the block, which will be a short piece of a cone of large diameter: when the hoop was turned, I took it off, cut and opened it straight again. The next step was to have a piece of steel bent into the form as per margin, [Fig. 1109,] which had two small holes bored in it of equal bigness, one to receive a small pin, and the other a drill of equal size. I ground the holes after they were hardened, to make them round and smooth. The chaps formed by this steel plate were as near together as just to let the long plate through. Being open at one end, the chaps so formed would spring a little, and would press the long plate close by setting in the vice. Then I put the long plate to a right angle to the length of the steel chaps, and bored one hole through the long plate, into which I put the small pin; then bored through the other hole; and by moving the steel chaps a hole forward, and putting in the pin in the last hole, I proceeded till I had

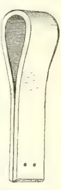


Fig. 1109.

divided the whole length of the plate. The next thing was to make this into a circle again. After the plate was cut off at the end of the intended number, I then proceeded to join the ends, which I did thus: I bored 2 narrow short brass plates as I did the long one, and put one on the inside and the other on the outside of the hoop, whose ends were brought together; and put 2 or 3 turned screw-pins, with flat heads and nuts to them, into each end, which held them together till I riveted two little plates, one on each side of the narrow plate, on the outside of the hoop. Then I took out the screws, and turned my block down till the hoop would fit close on; and by that means my right line was made into an equal divided circle of what number I pleased. The engine-plate was fixed on the face of the block, with a steel hole fixed before it, to bore through; and I had a point that would fall into the holes of the divided hoop; so by cutting shorter, and turning the block less, I got all the numbers on my plate. I need not tell you that you get as many prime numbers as you please; nor that the distance of the holes in the steel chaps must be proportioned to the length of the hoop."

Graham was the first to point out the fundamental principle of original graduation, viz. that you can divide a given line accurately into two parts, but not into 3 or 5 equal parts. "If a line or an arc is to be bisected, the points of the beam-compass are placed *nearly* at the distance of half the line, or the chord of half the arc between the dots. One point is placed in one dot, and a faint arc is struck with the other point towards the distant dot, and this operation is repeated with the second dot as a centre. The two faint arcs will either include a small space, or leave a small space between them, which can be most accurately divided with a pointer by the hand, aided by a magnifying lens."

The Duc de Chaulnes, after perfecting the micrometer-microscope for reading off the divisions of astronomical instruments, first showed how it might be used in actual dividing. Two microscopes, having cross wires in the foci of their eye-glasses, were fixed to a frame, and considered as the points of a pair of beam-compasses: these were extended to a diameter of the circle, and two temporary pieces of brass, with divisions on them, were attached to the circle by means of wax beneath the microscope, so that the divisions bisected the crosses in them: the circle was then moved half round, and, if required, the position of the micrometers and pieces of brass was changed, and the operation repeated, until they were diametrically opposite. A cutting point was then placed over one division, and a fixed microscope over the other, so that when any division was brought to bisect the cross in the microscope, the cutting point made one diametrically opposite. By the process of trial and adjustment with bisections and trisections, the circle was divided into spaces of 10°: then, by obtaining the arc of 9° by trial in the arc of 180°, the circle can be divided into spaces of 1°, and by similar means into smaller spaces if required.

Ramsden appreciated the advantages of the micrometer-microscope, and used it for reading off the divisions of his circles and theodolites. Edward Troughton combined Graham's method of perpetual bisections with the Duc de Chaulnes's mode of reading off. Troughton's method is thus concisely stated in a short, but masterly article on Graduation, in the *Penny Cyclopædia*:—"We will suppose that a circle is to be divided originally. After the edge of the circle is very carefully turned upon its own centre, a small circular roller, 16 revolutions of which carry it exactly round the circle, is prepared and so fitted to the circle by a radial frame joining the two centres, that, on turning the frame round, the roller is also turned in an opposite direction by friction between the edges of the roller and circle. The roller is divided into 16 parts, and a microscope placed over the divisions, and as each division comes under the microscope a fine round dot is marked upon the circle, which thus receives an approximate division into 256 (or 2^8) equal parts. Troughton expected, that as the roller could be carried round the circle any number of times without over or under-lapping, it would also mark out equal portions at each revolution; but he found himself mistaken, and he therefore proceeded to examine the dots optically. Two microscopes, A and B, are fixed above the circle, nearly in a diameter, and the dots which are to determine the divisions 0° and 180° are bisected by them. The circle is then turned half-round, and dot 180° brought under A; if 0° at the same time falls exactly under B, the points are diametrically opposite; if not, the quantity and direction of the error is measured by the micrometer of B, half of which is evidently the error of dot 180°. The microscope B is then shifted and fixed over dot 90°, while A bisects 0°. By a quarter revolution of the circle, 90° is brought under A, and 180° under B, and the error, if any, measured and noted. In like manner the error of dot 270° is detected; after which the microscope B is again shifted and fixed over dot 45°, when the errors of dots 45°, 135°, 225°, and 315°, are determined. It is easily seen that this is exactly Graham's principle of perpetual bisection, only using an *optical* beam-compass instead of one with points, and registering the errors of the dots instead of cutting actual divisions. In this way Troughton proceeded by continual bisections to note the relative or apparent errors of the 256 dots. His next step was to compute the actual or true error of each dot, and to form a table. Suppose that in examining the 180° dot he found that the arc from 0° to 180° was less than the arc from 180° to 360 by 20″, he would conclude that the dot 180° was 10″ behind its true place. Again, let the arc from dot 0° to dot 90° exceed the arc from dot 90° to dot 180° by 30″. If 180° were right, 90° would be too forward by 15″; but as 180° is 10″ behind its true place, 90° will, on this account alone be 5″ behind [forward], and therefore, on the whole, will be 10″ too forward. The true errors of each of the 256 dots being thus computed, Troughton returned to the roller, and by help of a small sector, which revolved with it, and gave him an enlarged scale, enabling him at the same time to reduce the division into 256 parts into 360° mechanically, proceeded to cut the actual divisions on the circle. . . . . It is not worth while to divide a circle *originally* which is less than 2 feet in diameter. Very great care must be taken that the pivots, on which the circle turns, shall be perfectly true and sound. The circular line to be divided, and the rim on which the roller moves, are respectively drawn and turned from these pivots, and the figure of neither is a circle unless the pivots be so. The large collar of the mural circle on which the rim is turned is of steel, and several inches in diameter. It often happens that hard knots occur in the steel which ordinary tools will not touch, and it would be prudent in the artist to perform the finishing part himself with a diamond."

GRAIN, (from *granum*, a seed,) an old measure of weight, the smallest of those in use: it is about the weight of a seed of wheat-corn. By a statute of Edward III. (A.D. 1266,) it was enacted that 32 grains of wheat taken out of the middle of the ear and well dried, should weigh a pennyweight, of which 20 should make an ounce, of which 12 should make a pound. The pound troy of this period, therefore, consisted of 7,680 grains; but that afterwards adopted had only 5,760, because the pennyweight came to be divided into 24 instead of 32 grains. [See WEIGHTS AND MEASURES.]

"The weight of one grain is obtained for practical purposes without difficulty, by weighing a thin plate of metal of uniform thickness, and cutting out by measurement such a proportion of the whole plate, as should give one grain. But a much better plan is, to draw a given weight of ductile metal into very thin wire, and to cut from the wire that length which is the same proportion of the whole length as a grain is of the whole weight. In this way pieces of wire are obtained for chemical purposes, which weigh only the thousandth part of a grain; and even less weights might be obtained if it were necessary."

GRANITE. The composition and varieties of granite will be given in the APPENDIX, the present article being chiefly devoted to some particulars, as to the mode of extracting and working this valuable substance, and its use as a building material and for ornamental purposes. Strange to say, the systematic use of granite in these islands is comparatively recent. The rounded outlying masses of granitic-rock which were found on the surface, were long employed both in Aberdeen, and at Dartmoor, (our two great depositories of granite,) for building purposes; but until 1730 in the former case, and 1820 in the latter, the squaring and dressing of this intractable material, and the opening of quarries to obtain a larger supply, had been scarcely thought of. The first building of any large size erected in Aberdeen with dressed or squared stones of granite, was Gordon's Hospital, commenced in 1739; and even in this case, sandstone was employed to form the lintels and facings. The good people of Aberdeen were not fully alive to the value of the rough material so plentifully scattered around them, until about the year 1760, when the profits arising from its conveyance to London as paving-stones opened their eyes to its importance, and they found that the surface-granite could not meet this demand, and that quarries must be opened to supply it. In like manner, the detached blocks lying about on Dartmoor were used in the neighbourhood for many years previous to 1820, when quarried granite was first brought into the market by the Haytor Granite Company. The Foggintor quarry, on Dartmoor, worked by this company, is in some places 100 feet high, and is worked in benches, or like a huge irregular flight of steps. The method of detaching the masses of granite-rock from their natural beds,[1] is first to determine the points of least resistance, and then to sink holes in those points vertically or inclined, as circumstances may require; the diameters of these holes being regulated by the mass and the amount of resistance, and their depth by the thickness of the blocks to be detached. The holes are sunk by means of an iron rod, ending in a chisel-shaped edge of hardened steel. The rod is held by one man, who changes its position after every blow from the sledge-hammers of other men who stand around. These holes, when sufficiently deep, are charged with gunpowder, for the purpose of blasting the rock; the ordinary process of tamping confines the powder, and the fuse communicates the blast. This operation is most perfectly performed, where the smallest amount of powder will remove the largest mass of rock with the least breakage. From three to five thousand feet have been removed at one discharge. [See QUARRY.]

To bring these rough masses into shape, lines are drawn at the places of the proposed division, and holes bored along them, five or six inches apart, and two or three inches deep, by means of a jumper. Each hole is then filled with two half-round pieces of iron, called *feathers*, with an iron-pointed wedge between them, and these wedges are gradually and equally driven until the stone splits. The split is in general tolerably flat, but should it be otherwise, the large projecting portions are removed by boring holes sideways, and again using the feathers and wedges; or smaller flakes are *spalled* off, or scaled by means of axe-formed hammers. The last operation, so far as the quarry is concerned, is *scabbling* the surface with heavy pointed picks. The blocks are then ready for the mason. A process not unlike this is adopted by the Chinese, for the squaring of the granite in the neighbourhood of Hong Kong. The granite rock which formed the crust of the earth near the main land of Cow-loon, seems by some tremendous action from below to have been raised up from its bed, riven into fragments of every kind of shape and dimension, and left in that new arrangement to undergo the weathering effects of the atmosphere. In the course of time, the smaller pieces were dis-

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(1) This quarry forms a remarkable exception to the rule which generally applies to the harder crystalline rocks, for here the granite occurs in stratified beds, following pretty nearly the slope of the hill, and becoming thicker and more nearly horizontal the deeper they are situated.

integrated into a quartzose sand, while the larger were merely rounded and polished by the same action which reduced their fellows to powder. Large masses lie embedded in sand, and at sufficient intervals to allow the hewer conveniently to attack them with his hammer and wedges. He first draws a line by means of an inky thread, which he manages with his hand and foot; then makes holes along the line about a foot apart, by means of his hammer and chisel,—a very slow and tedious operation; finally he inserts iron wedges, and passes three or four times from one end to the other, driving the wedges in succession, until at length the hard rock yields and falls asunder, as if it were only a piece of limestone. A block thus removed is cut up into smaller slabs by a renewed application of the hard chisel and the iron hammer, the wedge and the iron maul or beetle, while the irregularities of the surface are beaten off in the same way.

As a building material, the granite of Aberdeen is considered the best which our island affords. Its light bluish white tint is not liable to be affected by variations of weather, and when highly dressed, its appearance is not unlike that of the best white marbles. It is remarkably fine-grained, and on that account is of greater absolute strength than many other granites which may be more varied and pleasing to the eye. Magnificent stones as it respects size have been supplied from the Aberdeen quarries, such as the pedestal of the bronze statue of the Duke of Bedford in London, and the columns which are placed as piers in the vaults of the Custom House. The price of granite varies with the size of the block, and such stones as the above cost in their rough state at the quarries from five to eight, and in some cases ten shillings per cubic foot. Seven hundred thousand cubic feet of squared granite were supplied by the Aberdeen quarries for the docks of the naval arsenal at Sheerness, at 4*s.* 11*d.* per foot, including coasting duty. The tender for Aberdeen granite to the Fishmonger's Company, when their new Hall was about to be erected, was to deliver it in London at the following prices:—For a stone weighing 15 tons weight, 10*s.* per cubic foot; for one weighing 12 tons, 9*s.* ditto; 9 tons, 8*s.*; 6 tons, 6*s.*; 5 tons, 5*s.* 6*d.*; 3 tons, 4*s.* 6*d.*; 2 tons, 4*s.*, per cubic foot. The vast strength of the Aberdeen granite may be estimated by the fact that a half inch cube of the best granite required a force of 24,556 lbs. to crush it, which force was supplied by the hydrostatic press.

The Aberdeen granite has now to sustain great competition with that of Devonshire, from the quarries of the Haytor Company. This is also light of tint, fine of texture, and obtainable in very large blocks. A stone tramway was early constructed to enable it to be shipped at Teignmouth, and the completion of the Plymouth and Dartmoor railway afforded ready transport for the granite of the western face of the moor, from Foggintor, and other places adjacent. The facilities with which these quarries are worked, are therefore very great. Strong timber stages with travelling frames, and upon the frames powerful traversing crabs, have been constructed, to avoid the labour and delay of lifting by the ordinary means of derricks and cranes. The travelling frames, with the crabs upon them, can be transferred from one line of scaffold to another, so that power may be accumulated to any extent on one stage, so as to operate on blocks of extraordinary size. And such can be obtained from these quarries, the horizontal disposition of the rock allowing of the removal of stone of fair forms, and of the largest size. As an instance of the durability of Dartmoor granite, it is stated that a slab, which had been used as a foot-bridge from time immemorial, on being turned up, exhibited on the other side a Roman inscription, showing it to be at least two thousand years old.

The application of granite and porphyry to purposes of ornament, is the work of recent times, so far as modern nations are concerned; but those who have examined the saloon of Egyptian antiquities, in the British Museum, and still better, those who have been privileged to inspect the remains of Egyptian sculptures on their primitive sites, will have viewed with wonder and interest the result of the immense labours of that people, in bringing to a high degree of finish, works, in these, the most intractable of all materials. After the lapse of three thousand years, these works exhibit a degree of polish, and delicacy of detail, which shows how well the material is fitted to brave the attacks of weather, and of still ruder invaders. The idea of employing the chisel on such hard and nearly imperishable materials, appears to have originated with the Egyptians, and despite of the enormous difficulties with which they have had to contend, they have succeeded in giving softness of expression and a fleshy appearance to the features of their colossal heads.

In modern times, the best works in porphyry and granite have been executed, until quite recently, by the Swedes. Their success in the fabrication of vases, slabs, &c. in this unpromising material, has made them celebrated in Europe. The beautiful proportions and high finish of the porphyry vase, exhibited by Sweden, in the nave of our Great Exhibition, attested the skill of the sculptors. The Swedes, after bringing the objects as near as possible to the required form with a pick, mount them in lathes driven by water power, and finish by grinding them with other lumps of porphyry, supplied with emery and water; the machinery being kept in action, with fresh gangs of men, day and night.

Some fine specimens of porphyry may be seen at the Polytechnic Institution, Regent Street. Among others, a table 5 feet 10 inches in diameter, tastefully inlaid with numerous pieces of various colours. The table stands on a finely fluted pedestal, and it is said that the whole work occupied five men for the period of seven years. Two splendid porphyry vases five or six feet high are to be seen at Chatsworth. These were presented to the Duke of Devonshire by the Emperor of Russia, as a specimen of a flourishing manufacture which has sprung up in a barren valley where the porphyry was found. The beautiful porphyry of Cornwall might be readily converted into similar articles of elegance.

The process of polishing granite is more tedious and difficult than porphyry, on account of the unequal hardness of the particles. Nevertheless, of late years, numerous vases, and other circular and ornamental objects, have been executed in the most admirable manner in polished granites and elvans, which occur of various colours and degrees of hardness. The first persons in the British isles to accomplish this task, were the Messrs. Macdonald and Leslie, of Aberdeen, who introduced highly polished granite as a domestic ornament in halls and saloons, and also fabricated from the grey granite of Aberdeen, and the rich red granite of Peterhead, an endless variety of ornamental articles. The grey is of close grain, and contains more mica than the red. The red granite abounds in felspar and quartz, intermingled with small specks of mica, and bears a strong resemblance to the syenitic rock from which the finest Egyptian monuments are made. Both are susceptible of a fine polish, which they retain unimpaired by the weather. Professor Traill, describing a visit to the works of the firm above named, says, that the blocks of granite, which can be obtained of almost any size free from flaws and imperfections, are sawn asunder by machines moved by a fourteen-horse power steam-engine. The saws are of soft iron plates, secured in a frame, and operate on the stone by means of quartz-sand and water, applied as in slicing marble. No emery is requisite, the particles of siliceous sand being sufficient to cut the quartz, the hardest material in the granite. Frequently, fourteen saws are used in a single frame; occasionally eighteen are at work on a single block of stone. The progress of the work is very slow: it requires a whole day to cut a groove two-thirds of an inch in depth in the granite. The slabs, when cut, are polished by moving one over the other, by appropriate machinery, siliceous sand being first interposed, and then emery of various degrees of fineness, until the required lustre is obtained.

The first dressing of the granite blocks into parallelopiped, cylindrical masses, or other curved forms, is performed by handpicks, with short handles and heads about 4 lbs. in weight, which the workmen, from long habit, wield with great dexterity. The surfaces are then made regular by means of well-tempered chisels, urged by iron mallets; the chisels require a very particular temper, which must be neither very hard nor very soft, else they would either lose their edge by chipping, or fail to cut the stone. In the more delicate kinds of work they require frequent sharpening. The chisel is held obliquely to the stone, and very small particles are removed at a time.

In polishing curved or circular forms, as vases, the article is fixed in a well-contrived lathe, and whirled round by machinery, while the sand and emery are applied to the surface by means of thick plates or bars of iron, previously forged to the various curvatures. A large vase, for instance, was first prepared by the chisel, its graceful curves being in that way accurately cut; while iron bars from an inch to an inch and a quarter in thickness, neatly forged to its various curves, were ready to be applied to it, when it was fixed in the lathe.

By these various means, articles of great beauty and elegance are produced; chimney-pieces, tables, seats, pedestals, vases of classic forms, mural tablets, and altar-tombs. The lettering on monuments is executed with perfect neatness and precision by first tracing the inscription with a dark or light crayon according to the colour of the stone, then tracing the outline by light strokes of a fine-edged chisel held nearly vertically. The lines are then deepened by a succession of similar blows, while the chisel is held very obliquely, removing the stone in the state of powder, so as to avoid chipping. Roman capitals are thus easily formed, but Old English or German letters are more difficult. These, however, are carved in granite with the same precision.

Campbell's monument to the late Duke of Gordon was transferred from the model to the granite, by Messrs. Macdonald and Leslie. It is the first specimen of a British statue of a single block of granite, and leaves no doubt of the good effect attainable in this substance, under modern treatment and appliances. This statue is a great ornament to the city of Aberdeen, as is also a noble fountain of Peterhead granite which stands in the market-house. This is an octagonal basin, constructed of polished blocks, from the centre of which rises a shaft ten feet high, supporting two circular cups or shallow vases, one placed over the other. The lowermost is formed out of a single block 7 feet 3 inches in diameter, and the upper has about half that width. A constant jet of water rises from the centre of the upper cup, flows over its edges into the lower vase, which again overflows in a thin sheet of limpid water into the basin below, whence water is drawn for the purposes of the market. Notwithstanding the labour of workmanship, granite objects are produced at a very moderate cost. The beautiful fountain just described was erected at a cost of only two hundred pounds. Polished slabs can be furnished at from twelve to fourteen shillings the square foot.

This material greatly exceeds marble in durability, especially in a climate like ours. Marble loses its glossy surface and contracts greenish stains, but granite retains its polish under all atmospheric influences, and does not become stained by vegetation. An inscription in granite, unless wantonly mutilated, may convey information to distant ages. Four granite columns, bearing a very high polish, ornament the King's Library, British Museum. There is also a highly interesting collection of polished ornamental works in granites, elvans, marbles, serpentines, &c. in the Museum of Practical Geology, together with a large number of six-inch cubes of the same, which form part of the series of building-stones examined by the Commissioners, previous to the building of the New Houses of Parliament. The Institution of Civil Engineers has also a collection of granites.

GRAPHITE. See Carbon, page 316.

GRAVER. See Engraving—Graduation, &c.

GRAVITY, SPECIFIC. Every substance in nature has, under the same circumstances, a weight *specific* or peculiar to itself; or, in other words, the same volumes or bulks of different substances contain variable quantities of matter. The comparative weights of equal bulks of different bodies are called their *specific gravities*, and the standard of reference is pure water at the temperature of 60° Fahr.

The specific gravity of a liquid is usually taken by means of a *specific gravity bottle*, graduated so as to contain exactly 1,000 grains of pure water. If this be filled with spirits of wine, and weighed in a balance, (together with a counterpoise for the weight of the bottle, which of course is constant,) it will weigh considerably less than 1,000 grains: in fact, the bottle will contain only about 917 grains of proof spirit; therefore, taking the sp. gr. of water as unity, 1 or 1·000, the sp. gr. of spirits of wine is 0·917. If, on the other hand, the bottle be filled with sulphuric acid, it will weigh about 1,850 grains: whence the sp. gr. of sulphuric acid is said to be 1·850.

In taking the specific gravity of solids, advantage is taken of the important fact, that when a solid is wholly immersed in water, it displaces a bulk of that liquid exactly equal to its own, and the solid appears to lose in weight; that is, it is supported by the surrounding water with a force exactly equal to the weight of the water displaced: hence, the difference of its weight in water from that of its weight in air, must be the weight of an equal bulk of water. Hence the rule for taking the specific gravity of a solid is, to weigh the solid in air, and afterwards in water, and having found the deficiency of the latter weight, to divide it by the former, and the quotient will be the required specific gravity. For example, a lump of glass is found to weigh in air 577 grains; it is then suspended by a horse-hair from the bottom of the scale pan, and immersed in a vessel of pure water, when it is found to weigh 399·4 grains; the loss therefore, or the weight of an equal bulk of water, is 177·6 grains; then 177·6 : 1 : : 577 : 3·2, which is the sp. gr. of the glass.

Solid bodies lighter than water, such as cork, may be weighed by attaching to them a mass of metal or glass, previously balanced in water for that purpose, which causing them to sink, the same method is adopted with the combined mass as in the example just given.

The specific gravity of a liquid is sometimes taken by an instrument termed a *Hydrometer*, the principle of which may be thus illustrated. A bulb of glass or other substance, immersed in water, is buoyed up by a force equivalent to the weight of an equal bulk of water; so, when immersed in any other liquid, it will be supported by a pressure equal to the weight of a similar bulk of that liquid. Thus, the above mass of glass lost 177·6 grains by immersion in water, and only 149 grains in spirits of wine: consequently these two amounts are the weights of equal bulks of water and spirit; therefore, 177·6 : 1 :: 149 : 0·839, the sp. gr. of the spirit.

The hydrometer is a hollow ball of glass or metal, with a weight below it, and a slender graduated stem above, so adjusted as to float at a particular mark in pure water. When immersed in a lighter liquid, such as spirit, the lateral pressure of the fluid particles which supports it being diminished, the bulb sinks, till a portion of the stem becoming immersed, its weight is decreased, and the balance again restored. The instrument may be adjusted to different liquids by movable weights, while the graduations of the scale are made to express the specific gravities by the degree to which it sinks.

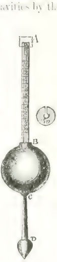

Fig. 1110.

Fig. 1110 represents Sikes's hydrometer, in which B is a brass ball, with a loaded stem C D, at the bottom, while above is a flat stem A B, graduated into 11 equal parts, each of which is subdivided into two. Eight circular weights (of which one is shown separately) are adjusted to the instrument: a slit cut in each admits the slender part C of the lower stem into the hole in the centre of the weight, and thus the instrument can be used in liquids heavier than water, but not in such as will corrode the instrument. A set of tables accompanies the instrument, by which the specific gravity of a spirit is easily ascertained, after observing the degree upon the stem to which it sinks. [See Alcohol.]

The specific gravities of aëriform bodies are ascertained by weighing them with certain precautions as to moisture and pressure in a thin glass globe or flask fitted with a stop-cock. The standard of comparison is dry atmospheric air at the temperature of 60° and 30 inches pressure.

The following table from Daniell's Chemical Philosophy, shows the weight of 100 cubic inches of the lightest and heaviest known forms of matter; of the same quantity of atmospheric air; and of water in its three physical states. The specific gravity of each, compared with air and water, is also shown.

	Cubic Inches	Weights.	Sp. Gr. Air being 1	Sp. Gr. Water being 1
Hydrogen	100	2·1[illegible] grains	0·0694	0·0000[illegible]46
Air	100	31·000 —	1·0000	0·001277
Steam	100	19·220 —	0·6240	0·000761
Ice	100	23775·000 —	766·000	0·940000
Water	100	25250·000 —	814·000	1·000000
Platinum .	100	542875·000 —	17512·000	21·500000

GREENSTONE is an intimate mixture of felspar and hornblende. See Hone Slates.

GRINDING and POLISHING, two important processes in the useful arts, variously applied, one for the production of *form*, and the other for that of *surface*. In the production of form by cutting, the material is mostly removed in chips and fragments, which in the case of metal admit of being reunited by fusion; but in the production of form by *abrasion*, of which grinding and polishing may be considered as the two extremes, the materials removed are ground to powder, and seldom admit of further application.

Most of the substances employed in the mechanical arts from the three kingdoms of nature admit of being ground and polished, by the application of certain abrasive surfaces or powders, applied by means of appropriate tools or apparatus. In some cases, the same substance may form the material to be polished, the polishing material, or the tool. For example, glass is ground and polished, as in plate-glass, cut-glass, and lenses; glass pulverised and glued upon paper is used as a polishing material; glass is also used as a tool or rubber, by means of which polishing powders are applied to metal works while being polished. So also with respect to iron, this metal is ground and polished in various forms; it is also used in the form of a disc or *skive*, with diamond powder, as a lap for polishing diamonds for jewellery; in the form of peroxide, or *crocus*, it is used for many purposes, such as polishing the specula of reflecting telescopes.

The grinding and polishing materials used in the arts, principally consist of *carbon*, as in the *diamond*, and compounds of alumina and silex in various degrees of crystallization and admixture, and usually combined with oxide of iron or lime; such are *sapphire*, *ruby*, *corundum*, *emery* and *rotten-stone*; *flint*, *tripoli*, *polishing-slate*, *Bohemian stone*, *Turkey-stone*, and *pumice-stone*; *oxide of iron*, *oxide of tin*, and *chalk*, are also used as polishing powders.

Some abrasive substances are used in the solid form, as the *grind-stone*, *oil-stone*, *hones*, *charcoal*, *Dutch-rush*, and *fish-skin*; a few are pulverised and mixed with various cements, as the grindstone and razor-hone of the Hindoo (described under EMERY, page 596); crocus mixed with wax is also used by our opticians. But the polishing powders having been separated into grains of similar magnitude (as described in EMERY), are usually applied by means of metal, wood, paper, leather, cloth, or bristles, proceeding gradually from the coarser to the finer powder, as the form of the work becomes gradually developed. The grinding powder is of course harder than the substance to be ground, but the implement or grinding tool is softer, and generally agrees in form with the analogous cutting or moulding tools used for producing work of corresponding shapes in other substances. Thus turned works are often polished with wooden tools, applied with the powders; flat works require factitious saws, files, and planes; a convex surface requires a concave grinding tool, and so on.

Great care must be taken in polishing to prevent the different powders and materials from becoming mixed. A grain or two of a coarse powder mixed with the fine, would produce deep scratches, and entirely nullify the effects produced by the powders of intermediate degrees of fineness. Hence, great cleanliness is required on the part of the operator, and between every two stages of polishing, there ought to be a careful rinsing of the work with water, and the entire removal of the previous materials used.

For special details respecting grinding and polishing, we must refer to separate articles. The grinding and polishing of Earl Rosse's specula are described under CASTING AND FOUNDING, p. 349. See also GLASS — LENS — EMERY — CUTLERY — MARBLE — LAPIDARY WORK, &c.

GRINDSTONE. A large variety of sandstone grits are used in the arts for grinding articles into shape, or for giving them a smooth and polished surface. They are formed into flat circular stones, called grindstones, of different diameters and thickness, and made to revolve with different degrees of velocity. When not in constant use, they are commonly turned by winch handles; but at Sheffield, Birmingham, and other places, where they are in constant use, they are mounted in large grind or blade-mills, and are turned by straps acting on their axles, the moving power being either water or steam. [See CUTLERY.] The following are a few of the substances used for the grindstones in common use: 1. *Newcastle grindstones*, from the coal districts of Northumberland, Durham, Yorkshire, and Derbyshire, are selected of different degrees of density and coarseness, for the various manufactures of Sheffield and Birmingham. 2. *Bilston grindstone* is similar to No. 1, but of a lighter colour, much finer, very sharp, but not too hard. It is confined to a small spot of limited extent and thickness, near Bilston, in Staffordshire, where it lies above the coal, and is quarried entirely for the purpose of grindstones. 3. *Carpenter's rubstone* is a hard, close variety, used as a portable stone for sharpening tools by rubbing them on the flat stone instead of grinding. It is also used for giving a smooth and uniform surface to copper plates for the engraver. A much softer variety of sandstone is usually cut into a square form, from 8 to 12 inches long, in which form they are used dry by shoemakers, pocket-book makers, cork cutters, and others, for giving a rough edge to thin-bladed knives, &c. 4. *Devonshire batts*, a porous, fine-grained sandstone, in considerable repute, from the quarries of Black Down Cliffs, near Collumpton. 5. *Yorkshire grit* is used as a polisher of marble, and of copper plates for engravers. 6. *Congleton grit*, a similar, but softer stone, and similarly applied. 7. *Sheffield grindstone* is a hard coarse grit used for grinding large files, &c.; it is obtained from Hardsley, about 14 miles north of Sheffield. 8. *Wickersley grindstones*, from Wickersley, about 9 miles east of Sheffield, are used for most purposes of grinding, as knives, scissors, razors, saws, and edge tools. 9. *Sheffield bluestone* has a finer grain than No. 7 or No. 8, and is used at Sheffield for finishing the grinding of articles of cutlery that have been prepared on No. 8. The bluestones are found in abundance on the north and south sides of Sheffield. Grinding on a bluestone is called *whittening*. See HONE-SLATES, and also Mr. Knight's paper in the Transactions of the Society of Arts, vol. l.

GRIT. A variety of sandstone to which distinctive terms are applied in particular districts, as *mill-*

stone grit, *red grit*, *white grit*, *grindstone grit*, &c. In the North of England, the term *freestone* is applied to such gritstones as will work easily, and with a good face: *calliard stones* are intractable, close grained, almost flinty grits; *hazel* is applied to some hard grits in Aldstone Moor, Cumberland; at Newcastle, the word *post* signifies a *bed*, and is generally associated with gritstone rocks. The *calcareous grit* of Geology, is part of the middle oolite formation. *Millstone grit* contains beds of quartz pebbles, and is a coarse irregularly laminated rock.

GROATS, or GRITS,(1) oats desiccated or deprived of their husks, and used to form a decoction with water, called water gruel. When bruised ready for use, they are called *Embden grits*, or *prepared*, or *patent grits*. When taken as an article of nourishment, a larger quantity of grits should be used than when required as a demulcent or diluent to promote perspiration in the early stage of a cold; in the latter case, the addition of butter, spices, wine, &c. must be avoided, and only a little sugar or salt used.

GROINS, the lines formed by the intersection of arched vaultings. Such intersections are called *groinings*, and the vaultings *groined arches*. They appear to have originated in the accidental intersection of arches, and afterwards to have formed the basis of an extensive system of decoration, as exhibited in the ceilings of many of our ecclesiastical structures. Groined arches are constructed with stone, brick, wood, and plaster. With the first two materials, a centering of wood is used to turn the arch, and form its groins. "The centering consists of several ribs dispersed at 3 or 4 feet distance, made to the size of the vault which has the greatest opening. The extremities of these ribs rest on beams supported by standards, and are boarded over without any regard to the transverse openings, which are afterwards formed by another set of ribs adapted thereto, and then boarded so as to meet the boarding of the first vault, which, if of considerable breadth, must have short ribs fixed upon its surface, in order to shorten the bearing of the boarding of the transverse opening; and thus the centering will be completed. . . . It is obvious, that in forming the ribs for each vault, the outer curve must be the arc of a circle, or ellipsis, within the curve of the vault, and distanced from it towards the axis equal to the thickness of the boarding. In making the groined centre, it will be necessary to find the place of the angles on the boarding of the large vault, in order to ascertain the place of the ribs and boarding of the transverse vault. This may be done by three different methods. First, let two straight edges be placed vertically at the angles, and a third straight edge, or an extended line, be made to touch the surface of the boarding, and marked at all the points of contact, keeping the latter straight edge or line always upon the edges of the two vertical straight edges. The defect of this method is, that the place of the angles at the bottom can never be found, since it would require the cross straight edge or line to be of infinite length, and the vertical ones of infinite height. A more eligible method therefore, where there is room, is, secondly, to fix two ribs in the transverse part, and direct a level straight edge upon their edges, so that the end may come in contact with the boards, and mark the boarding in this place; find a sufficient number of points for the purpose in the same manner, and draw curves through the points, which will give the curves for fixing the end of the filling-in ribs, otherwise called *jack-ribs*. In constructing groins to be finished with plaster, the angle must be first fixed, then straight longitudinal pieces parallel to the axis of the groin fixed, either flush with the under side of the angle ribs, or their under sides a little below those of the angle ribs, so as to admit of their being nailed together; this is the most eligible method of constructing plaster groins."(2) [See BRICKLAYING.]

GUDGEONS are the ends or extremities of a horizontal shaft which runs in the collar; they are made as small as possible consistently with their strength. The cube root of the weight of a water-wheel in hundredweights is found to be nearly equal to the diameter in inches of a cast-iron gudgeon strong enough to support it. Gudgeons of cast and of wrought iron are in the proportions of 9 to 14. Those parts of a shaft which revolve between the points where the power and resistance are applied, are called *journals*, and the diameter of these as well as of gudgeons serves in some degree to proportion the shaft. The axis of the gudgeon should always be in the line with the axis of the shaft. When water-wheels are of timber, their diameter in feet, multiplied by the width in feet, plus the square of half the diameter, will give a sum, the cube root of which is the diameter of the gudgeon in inches. Spindles to grindstones, or to other wheels, may be calculated in the same manner.

GUM. A term applied to several modifications of a distinct proximate principle of vegetables, of more universal occurrence than any other secretion by plants. Some of these modifications are termed *mucilage*.(3) In fact, gum is the material usually prepared by plants for their own nutrition; in which state it is in solution; but when the bark is wounded either by the knife, by the puncture of insects, by disease, or by means of certain fungi, the solution escapes to the surface, thickens, and even becomes solid and pulverizable. The gums are characterised by forming a viscid, adhesive, or mucilaginous solution with water, and by being insoluble in alcohol; so that the addition of spirits of wine to a moderately strong aqueous solution of gum causes the separation of a white precipitate or magma, in consequence of the achohol combining with the water, and the gum, having nothing to hold it in suspension, falls down. Another characteristic of gum is its convertibility into mucic or saclactic acid by the action of nitric acid.

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(1) The word *grit* is usually applied to small particles of stone, or hard grit: thus, *sandstone grit* consists of small siliceous particles; but as applied to shelled oats, the word appears to be derived from the dropping of the *s* in *grist*, which is corn or grain bruised or crushed.

(2) Nicholson's Architectural Dictionary.

(3) When certain seeds or roots are infused in water at 160° or 180°, subjected to pressure in a linen strainer, and the liquor evaporated, the residue resembles gum. Bruised linseed treated in this manner may be made to yield a substance closely resembling Gum Arabic.

There are two leading modifications of gum, one of which is represented by *Gum-Arabic*, and the other by *Gum-Tragacanth*; there are many intermediate varieties, amongst which *Cherry-tree Gum* may be distinguished: the different kinds of gums have been classed under the generic terms of *Arabine*, *Tragacanthine*, and *Cerasine*, (from *cerasus*, a cherry-tree.)

GUM-ARABIC is the produce of several species of acacia growing in Arabia, India, Upper Egypt, Senegal, &c. It occurs in rounded pieces, or *tears*, and in fragments, up to the size of a walnut, or larger: these are of irregular shape: the colour is either white, yellowish, or dark wine yellow; there is scarcely any odour, and the taste is mawkish and glutinous; the sp. gr. varies from 1·30 to 1·50. It breaks readily into small irregular pieces, with an uneven vitreous fracture. It dissolves almost completely in water; 100 parts of water at 212° Fahr. take up 19 parts of gum. The solution is, however, purer when made with cold water, and keeps better: it is sometimes used as a glaze or varnish, and for the purpose of giving a gloss and stiffness to ribands, calico, &c. The sp. gr. of the solution being greater than that of water, many substances in a state of minute mechanical division which will subside in water, will not do so in mucilage: hence the use of gum in writing ink and in some paints, and in the pigments used in calico-printing, &c. When gum is sold in powder, it is often adulterated with starch, the presence of which may be detected by tincture of iodine, which strikes a blue colour; or when cold water is used for the solution, the starch remains undissolved. Gum is highly nutritive, and is used in medicine as a demulcent. The term *Arabine* is applied to Gum-Arabic. Its composition is $C_{12}\,H_{11}\,O_{11}$. Its specific gravity varies from 1·3 to 1·5. The term *bassorine* is given to the variety of tragacanth that comes from Bassora. *Gum-Senegal*, from the island of that name on the coast of Africa, is largely used by the calico-printers instead of Gum-Arabic.

GUM-TRAGACANTH is the produce of certain species of *Astragalus*, growing in Asia Minor, Armenia, and Northern Persia. It is usually in the form of white or yellowish semi-transparent flakes, or curled vermicular pieces, which are very tough, and require, before they can be powdered, to be dried at 212°, when they lose about 10 per cent. of water, and become brittle. When steeped in water this gum swells into a bulky mucilaginous mass, which, when boiled with water, gradually acquires the appearance of a solution of ordinary gum. 100 parts of tragacanth yield 53 of arabine and 33 of tragacanthine, or *bassorine*, a mucilaginous substance forming the bulk of *Gum Bassora*, the remainder being water and oxalate of lime. Gum-tragacanth is used for some of the purposes to which gum-Arabic is applied. It is often sold in the shops as *gum-dragon*.

CHERRY-TREE GUM, including that of peach and apricot-trees, and other species of *Prunus*, resembles inferior gum-Arabic in its external characters, but is only partially soluble in cold water. It differs from it in some of its chemical relations.

GUM-RESINS are vegetable secretions which are most abundantly and most perfectly produced in warm countries, from trees and shrubs of particular tribes of plants, but rarely from herbaceous plants, except the large herbaceous umbelliferæ, which yield the fœtid gum-resins. They either exude spontaneously, or from incisions made in the stem and branches. "When they first escape to the surface they are fluid, and of a light colour, but gradually harden and become of a deeper hue, either by the evaporation of some of their volatile oil, or by the absorption of oxygen from the air and the conversion of the oil into a resin. Some remain in a semi-liquid, viscid state, such as *sagapenum* and *galbanum*, which are only pulverizable in winter. Most gum-resins possess a strong odour, (which in many instances is disagreeable, such as that of *asafœtida*,) with a warm acrid taste, and by application to the skin for any considerable time, they cause redness and inflammation. Owing to their composition being a mixture of gum and resin, they are not completely soluble either in water or absolute alcohol, but are perfectly dissolved in proof spirit, which is much employed to prepare tinctures of this class of substances. The gum, being soluble in water, is capable for a time of holding the resinous portion suspended in water, thereby forming an emulsion, a state which admits of their administration, if used soon after being prepared; for by rest they separate. Many of them are soluble to a certain extent in acetic acid, especially when assisted by heat. The strong mineral acids char them, and produce chemical changes. Many gum-resins are popularly termed *balsams*, a designation to which they have no title, as they do not contain benzoic acid."

ARTIFICIAL GUM. In the processes of calico-printing and for stiffening different goods, an artificially prepared gum has for some years been employed. In the article BEER, page 112, it is stated, that starch or fecula is by the action of diastase, a peculiar azotised substance formed during the germination of seeds, converted into a gummy mucilaginous substance named *dextrine*. It is also known in commerce under the name of *British gum* and *torrefied starch*. The term *leiocome* has been applied by Payen to a modified dextrine, whiter and more soluble than can be obtained by torrefaction. It is formed by moistening 1,000 parts of dry starch (potato starch is generally used) with very dilute nitric acid, consisting of 2 parts of concentrated acid and 300 of water: the mixture is divided into small blocks, which, when dried in the air, are rubbed down and exposed in a proper drying-stove to a current of air heated to about 150° or 160°: the powder is afterwards well dried at a temperature not exceeding 230°. When well made it dissolves in cold or tepid water as easily as gum-Arabic.

From a recent paper by M. Emile Thomas, quoted in the *Chemical Gazette*, it appears that artificial gum is manufactured in three distinct forms; viz. as a white, brilliant, pearly powder; as a syrupy solution; and in the form of exotic gum in greater or less perfection, either broken into small fragments, or made into rolls of various sizes.

Dextrine is manufactured either by the use of acids or by means of the diastase contained in malted barley. When sulphuric acid is used, the dextrine is deliquescent, and the products often coloured: hence this acid is not used. Pure nitric acid is commonly employed for obtaining dextrine in the state of powder, as in M. Payen's process. Muriatic acid is also used for rendering the starch soluble, and it is then dried at a high temperature. The powder thus obtained is thrown upon a metallic sieve, and submitted to the action of a jet of steam, which moistens the dextrine so as to render it transparent without liquefying it: after this it requires very little drying. This process, however, requires more skill than can be expected of an ordinary workman.

The process by diastase seems to be the most advantageous. The fecula is rendered soluble in vats heated by steam in such a manner that the temperature may be easily raised or lowered. The fecula is first mixed with 4 times its weight of water at about 122° Fahr. At one operation about 600 lbs. of fecula are mixed with 1,200 quarts of water. The temperature must be kept at about 140° until the whole mass is converted into starch; 2 per cent. by weight of very white malted barley is then added, and also the mucilage produced from 1 per cent. of linseed. If a larger proportion of malt were used, the decomposition would be more rapid, but a larger quantity of glucose would be formed, and the gum would be more coloured. The mucilage of linseed imparts tenacity to the gum. The mixture must be kept at about 120° or 140° until all the starch is again dissolved; the temperature should then be suddenly raised, taking care, however, not to exceed 167°, but keeping as near that temperature as can be in order to cause the diastase to act as powerfully as possible. The mixture is then to be well stirred until the decomposition is almost complete: this may be ascertained by testing with iodine, which ought to give a violet approaching to red, instead of the characteristic blue tint. During the decomposition the liquid must be kept constantly in motion: the operation lasts about an hour and a quarter; that is to say, a quarter of an hour for the formation of the paste, one for its dissolution, and the other three-quarters for rendering it soluble. The liquor is then removed from the decomposing vats, and left in pans to settle for from 6 to 18 hours, according to the external temperature. During this time a slight fermentation will be perceptible, but it must be checked by adding alum in the proportion of 10 grammes for every 25 gallons of liquid. By allowing this time for the mixture to settle, the colouring of the gum while being baked is avoided. When drawn off, the liquor will mark about 10° B: it is then evaporated by raising it very slowly to the boiling point, the perfect clarification being accelerated by checking the first boiling, as in refining sugar. This clarification is effected without any foreign agent, by the coagulation of the vegetable albumen contained in the malt and the linseed mucilage. The scum which rises to the top must be carefully removed. If the boiling be hastened, the gum will first become thick, and afterwards be coloured. When a solid pellicle of gum forms on the surface the baking will be completed, at which time the syrup will mark about 35° B. If the gum is to be kept in a liquid form, the baking must be stopped at 30° while boiling, and the syrup be poured into well-closed vessels, previously rubbed with oil of turpentine, and the surface of the gum be covered with a thin layer of that oil. This method is tolerably successful in preventing fermentation. When it is desired to solidify the gum, the boiling syrup is poured into small flat tin vessels, placed upon a hot-air stove, kept at a temperature of from 104° to 122°. At the end of 24 hours the gum will acquire the consistency of jujube-paste: it is then to be cut up with a pair of shears into small oblong pieces, and these are to be rolled out upon a polished table with a wooden roller, dusted with pulverized artificial gum, and afterwards placed upon wooden frames, and left for 3 or 4 days to dry. The artificial gum, thus prepared, dissolves easily, and makes a very clear solution.

GUN. Agreeing with the remark of Fenelon, in his "Telemaque," that to be always prepared for war is the surest way to avoid it, we must regard with interest the details respecting the manufacture of fire-arms. Large guns or cannon appear to have been used by Edward III in his first campaign against the Scots in 1327. At the battle of Cressy, in 1346, they occasioned much terror and surprise in the enemy. Other accounts state that the French used cannon in 1338, and gunpowder at the siege of Algiers in 1342. In 1378 the English are said to have used 400 cannon at the siege of St. Malo, but these were probably hand-cannon or culverins. In 1418 we read of stones being used as shot, and these were often of very large size, being hooped together with iron rings in masses of 1,200 lbs. weight. As knowledge increased, its improving influence extended even to weapons of destruction: cannon were reduced in size, and cast in iron and bronze; and iron bullets were first used in England in 1550. Cannon continued to be cast in a very clumsy form for a great number of years, until it was proposed by Monk to remove a quantity of useless metal from before the trunnions, and increase the thickness considerably where alone it is required, viz. at the breech end. A 56-pounder cannon, cast on this plan, was tried at Deal in 1839. It was 11 feet long; the diameter of the bore was 7·6 inches; the weight 98 cwt.; the windage 0·175. At an elevation of 32°, with a cast-iron shell filled with lead, weighing $62\frac{1}{3}$ lbs. and 16 lbs. of powder, the range was 5,720 yards, or $3\frac{1}{4}$ miles, the greatest distance which had ever been attained by any projectile with any charge whatever, and the greatest velocity, the whole time of flight being only 30¼ seconds, which is estimated at 2,100 feet in the first second. Guns on this plan are several hundredweight lighter than on the old one, and they recoil less. It was found, contrary to the received opinion, that by increasing the windage the range was increased; because in long guns, if the bullet fit the bore closely, and a great velocity be desired, the column of air to be displaced before the ball quits the gun is considerable, and is condensed so rapidly, that it offers immense resistance to the passage of the bullet; but by reducing the size of the ball, so as to increase the windage, the air has more space to rush round it and hence the ball escapes with greater facility.

The casting of large guns is noticed under CASTING AND FOUNDING, p. 344; and the boring of the same, under BORING, p. 163; see also APPENDIX.

Hand-guns, or small fire-arms, appear to have been introduced in 1471, when Edward IV., landing at Ravenspur, in Yorkshire, brought with him, among other forces, 300 Flemings armed with hand-guns. After this they became common. At first they were fired by the application by hand of a lighted match to the touch-hole. This was improved by the invention of the *match-lock*, a contrivance suggested by the trigger of the cross-bow, to convey with certainty and instantaneous motion the burning match to the pan: hence the weapon was called *arquebus*, or *harquebus*. The match-lock was superseded by the *wheel-lock*, a small apparatus for exciting sparks of fire by the friction of a furrowed wheel of steel against a piece of sulphuret of iron, which, from such application, acquired the name of *pyrites*, or *fire-stone*. The fourth great improvement was the *flint-lock*, which continued from the time of Elizabeth to the present century, when the invention of the *percussion-lock* has superseded all other forms.

The essential accompaniment of the percussion-lock is the *percussion-cap*, an invention which passed through many stages of progression before it attained its present exquisite simplicity. The application also of a proper fulminating powder was long a matter of great difficulty. Fulminating mercury was found to be uncertain in its action, on account of the extreme rapidity of its combustion, passing through and scattering the gunpowder without igniting it, just as the discharge of a Leyden jar is known to do. But as gunpowder can be easily fired by electricity, if means be employed to retard the amazing velocity with which the fluid moves, such as making a piece of wet string form part of the line of discharge, so by mixing a more slowly burning substance with fulminating mercury, the desired effect is produced. For this purpose 6 parts of *pulverine*, or meal-gunpowder, with 10 parts of fulminating mercury, form a good composition for priming copper caps.

The introduction of percussion caps led also to the necessity of altering the breeching of guns. The breeching or plug of a gun was formerly a solid lump of iron screwed into the barrel close to one end, the touch-hole being drilled through the side of the barrel above it. Long before the introduction of percussion caps it was a matter of complaint that these guns fired very slowly, and that a considerable portion of the powder was blown out uninflamed, so that much force was lost. A great improvement was made by Nock, in 1787, who introduced a form of breeching, Fig. 1111, which caused the powder to be ignited in the centre: this method was found to be safer; it did not cause the gun to leak by long-continued use, it greatly improved the strength and regularity of shooting, and it prevented the gun from becoming partially foul. This breeching continued in use for fifty years without any real improvement, but when percussion caps came into use, there was a complaint that they did not shoot so strong as the old flint guns. This led to the invention of other forms of breeching, of which that by Mr. Wilkinson, Fig. 1112, has been approved.

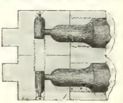
Fig. 1111

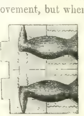
Fig. 1112.

The locks of guns have also passed through a great variety of changes. Indeed, as Mr. Wilkinson observes,[1] "there is probably no branch of the mechanic arts that has so much occupied the attention of persons unconnected with it professionally, as the improvement of fire-arms, either from its importance in a military point of view, or from the importance attached to its perfection by all sportsmen. The consequence has been, an inundation of alterations, few of which deserve the name of improvements; and they have been gradually or speedily forgotten, according to their comparative merits. One great error into which amateur improvers of fire-arms are very liable to fall, is their forgetfulness of the action of gunpowder on metals, particularly when exposed to the influence of a damp atmosphere. Many ingenious contrivances are annually produced, which, but for this circumstance, might continue to act perfectly well, and if the same mechanism were applicable to other purposes, would do credit to the inventors. Another error is that of making experiments on too diminutive a scale, and arguing that if successful with a pistol or a musket, the same plan will prove equally efficient with a cannon: nothing can be more fallacious, or more common. As these errors arise from a want of practical knowledge, I merely notice them in consequence of having been so often applied to, confidentially, for my opinion of inventions for which patents were about to be obtained; and I have frequently, in vain, attempted to convince the parties that success was absolutely impossible; for as parents feel greater affection for their own children than for those of others, so it is with projectors and their inventions. Few persons are aware of the immense force with which the flame rushes from the vent hole

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(1) Engines of War, by Henry Wilkinson, M.R.A.S. London, 1841.

of a large cannon when loaded with its service charge. An experiment made at Woolwich affords a striking illustration of the fact: a cannon ball weighing 24 lbs. was placed exactly over the vent hole of a loaded 32-pounder cannon, which was fired by a train of gunpowder, when the rush from the vent projected the 24-pounder ball to a very considerable height in the air, although the diameter of the hole was only $\frac{2}{10}$ inch. This is one of the causes which renders the application of the percussion system to cannon more difficult than might at the first glance be imagined; and, in order to prove the necessity of making all experiments in gunnery on as large a scale as it is ever intended to apply to the same principle, I will illustrate it by a failure of my own. Conceiving that this difficulty would be overcome if the cock struck round the vent hole, leaving a large conical space in the centre for the escape of the flame, I constructed a cannon-lock on this principle, which was tried on board the *Excellent* at Portsmouth, and found to succeed perfectly with 12-pounders, and even with 24-pounders not shotted; but when fully charged, the lock was broken. I have since constructed a very cheap and simple one, which answers perfectly."

The manufacture of a gun is rather a complicated affair; but we will endeavour, with the assistance of Mr. Wilkinson's well-written little volume, Mr. Greener's two excellent works,[1] and our own observations in the workshops of Birmingham, to convey a concise but adequate description of the same; we shall, however, confine our notice chiefly to the best made guns, which are for the most part finished in London, the separate parts being supplied in the rough from the country. The muskets and cheap guns manufactured at Birmingham go through the same processes as the best guns, but fewer hands are concerned in the manufacture, and less care is bestowed upon them.

Every best-finished gun usually passes through 15 or 16 hands, each of which represents almost a distinct trade. They may be arranged in the following order:—1, Barrel-forger; 2, lock and furniture forger; 3, barrel borer and filer; 4, lock filer; 5, furniture filer; 6, ribber and breecher; 7, stocker; 8, screwer-together; 9, detonator; 10, maker-off; 11, stripper and finisher; 12, lock finisher; 13, polisher and hardener; 14, engraver; 15, browner; 16, stock polisher.

Forging.—The forging of gun-barrels varies according to the quality intended to be produced, or the use to which the barrels are to be applied. Musket or common barrels were formerly made from what are called *skelps*. The skelp is a piece of iron about 3 feet long and 4 inches wide, but thicker and broader at one end than at the other; and the barrel was formed by forging out such pieces to the proper dimensions, and then folding or bending them round into a cylindrical form until the edges overlapped, so that they could be welded together. Mr. Babbage, in his "Economy of Manufactures," informs us how these methods of forging and welding came to be abandoned. Some years ago, the men employed in an extensive factory in forging these skelps, struck for higher wages, and their demands being exorbitant were not complied with. While the dispute was pending, it occurred to the superintendent that if the circumference of the rollers between which the bar iron was rolled were to be made equal to the length of a skelp or of a musket-barrel, and if the grooves in which the iron was compressed, instead of being equally deep and wide, were cut gradually deeper and wider from a point in the rollers until it returned to the same point, then the bar iron passing between such rollers, instead of being uniform in width and thickness, would have the form of a skelp. The plan was perfectly successful, and the services of the refractory skelp-forgers were no longer required. Such is the moral to be read from the history of every strike; but so difficult is it for us to profit by the experience of others, that this severe lesson was lost upon the skelp-welders. A contract having been entered into for a considerable supply of gun-barrels to be delivered on a fixed day, the men struck for such an advance of wages as would have caused the completion of the contract to be attended with a heavy loss. Under these circumstances of difficulty, the contractor turned his attention to the perfecting of a process which some years before had been patented for welding gun-barrels by rollers. The plan was so successful that it greatly surpassed the results of hand labour. The process consisted in turning a bar of iron about a foot long into the form of a cylinder with the edges a little overlapping. It was then raised to a welding heat, and a triblet or cylinder of iron being placed in it, it was passed quickly through a pair of rollers. The welding was thus performed at a single heating, and the remainder of the elongation necessary to bring it to the length of a musket-barrel was performed in a similar manner, but at a lower temperature. This invention broke up the combination, and brought in a class of men at considerably lower wages. After this, there was no hope that the skelp-welders could ever recover the position they had forfeited; for not only was the work done better and cheaper, but the new method was found to be less injurious to the texture of the iron, which was now exposed only once instead of three or four times to the welding heat. The new process was also found to be adapted to the manufacture of iron tubes for the conveyance of gas or of water for warming houses.

Barrels for fowling-pieces are known as *stub*, *stub-twist*, *wire-twist*, *Damascus-twist*, or the two latter combined; also *stub-Damascus*. There are also a variety of inferior kinds, which do not require notice.

Stub iron is formed from old horse-shoe nails, called *stubs*; this form of iron being preferred on account of its excellence obtained by repeated workings; for if the iron were bad, the nails could not be driven into the horse's hoof. The stubs are packed closely

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(1) "The Gun, or a treatise on the various descriptions of small fire arms," by William Greener. 1835.

"The Science of Gunnery, as applied to the construction of fire-arms," by the same. 1841.

together, bound with an iron hoop into a ball 10 or 12 inches in circumference, raised to a welding heat, united by hammering, and then drawn out into bars of convenient length. This method is adopted for the locks, furniture, and breechings, of the best guns, and also, to some extent, for barrels. The quantity of nails that can be obtained in this country is not adequate to the demand, so that immense numbers are imported from France, Holland, Sweden, and other parts, in casks, containing from 16 to 18 cwt. each. For the manufacture of gun-barrels they are sorted and picked, to separate cast-iron and impurities, and about half a cwt. are then put into a large cast-iron drum, crossed internally with iron bars, through the centre of which a shaft passes, which is connected by a strap with the steam-engine, and the revolution of the driver polishes the nails by their friction against each other: the dust is then separated by sifting. The stubs alone would produce too soft a metal: a portion of steel is therefore mixed with them, varying from $\frac{1}{8}$ to $\frac{1}{2}$ of the whole mass. The steel is clipped into pieces corresponding in size with the stubs. About 40 lbs. are then thrown on the hearth of an iron-furnace, and they are puddled or mixed together with a long iron rod, and the bloom thus formed is welded under a hammer of 3 tons weight, to a long square block; this is then raised to a bright red heat, and drawn out under a tilt hammer into bars of the proper size to pass the rollers, by which it is reduced to rods of the required size. The iron thus produced is very tough, and free from specks or *greys*.

Stub-barrels are also made from *scrap*-iron, which consists of the cuttings from various manufactories, the cuttings and punchings of sheet-iron, as well as worn-out articles in iron. These are sorted and used in preparing iron of various qualities, known as *wire*-twist, *Damascus*-twist, *stub* twist, *charcoal*-iron, *threepenny skelp*-iron, *twopenny*, or *Wednesbury skelp*, *sham-damn-skelp*, &c. The scrap is cut into small pieces, the object being to cross and interweave the fibres in every possible direction, and thus to increase its tenacity. For the finest description of barrels, a certain proportion of scrap-steel, such as broken coach-springs, is cut into pieces and puddled in with the iron, whereby the steel loses much of its carbon and becomes converted into *mild* steel; it unites readily with the iron, and improves the variegation and beauty of the twist. For *twisted* barrels the iron is drawn out into ribands by rolling into lengths of several yards, and about $\frac{1}{2}$ inch wide, varying in thickness according to the part of the barrel to which the ribbons are to be applied. They are cut into lengths, each sufficient to form one-third of the barrel. One of these lengths is made red-hot and twisted into a spiral form, by placing one end in the prong of an iron rod, Fig. 1113, which passes through a frame, and is turned by a handle, the riband being prevented from going round without twisting, by means of an iron bar placed parallel to the revolving rod. The spiral thus formed is raised to a welding-heat, and dropped upon an iron cylindrical rod, which, being struck forcibly on the ground, (called *jumping*,) the edges of the spiral unite and the welding is completed by hammering on the anvil. The other spirals are added to complete the length of the barrel, and the forging is finished by hammering regularly all over. *Wire*-twist, of any degree of fineness, is obtained by welding alternate laminæ of iron and steel, or iron of two qualities together, and drawing the compound bar into ribands as before. The beauty of the barrel is increased by twisting, and also its strength, because the longitudinal direction of the fibres is thus opposed to the expansion that takes place in firing. *Damascus* iron, so called from its resemblance to the celebrated Oriental barrels and sword blades, is produced in various ways. "One method is to unite by welding 25 bars of iron and mild steel alternately, each about 2 feet long, 2 inches wide, and $\frac{1}{4}$ inch thick, and having drawn the whole into a long bar or rod, $\frac{5}{8}$ inch square, it is then cut into lengths of 5 or 6 feet. One of these pieces, being heated to redness, is held firmly in a vice to prevent it from turning, while the other end is twisted by a brace or by machinery, taking care that the turns are regular, and holding those parts which turn closer than the other with a pair of tongs: the rod is thus shortened to half its original length, and made quite cylindrical. If only two pieces are employed to form the riband, one is turned to the right and the other to the left; these being laid parallel to each other, are united by welding and then flattened; but if 3 square rods are used, the centre one is turned in a contrary direction to the outside ones, and this produces the handsomest figure. By these operations the alternations of iron and steel change places at every half revolution of the square rod, composed of 25 laminæ, the external layers winding round the interior ones, thus forming, when flattened into a riband, irregular concentric ovals or circles. The fineness of the Damascus depends on the number and thickness of the alternations; and the figure of the riband, when brought out by acids, resembles that of a curled ostrich feather; but when wound into a spiral form, and united on its edge by jumping, the edges bend round and the figure is completed." A thin riband of Damascus is sometimes veneered on common iron or gas tubing, so as to form gun-barrels of a very low price with a high-priced appearance. ***Stub-Damascus*** is only one square rod of Damascus iron twisted and flattened into the riband for forming the barrel. *Damascus and wire-twist* is a riband of each twisted together.

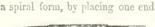

Fig. 1113.

Boring and grinding.—The barrel being forged, the next operation is boring, which is usually done by machinery. A long square bit, attached to a rod, is made to revolve rapidly while the barrel is pressed forwards by a crooked lever, held at one end by the workman while he passes the other along a series of pegs driven into the top edge of the trough or bench on which the barrel is placed, thus forcing the barrel forward along the boring-bit. The barrel is kept cool by water flowing constantly over it, otherwise the heat generated would destroy the bit. The outsides are then ground on very broad stones; for which purpose the man sits on a kind of wooden horse chained to the floor, and leans with the barrel against a sloping board nearly in contact with the grindstone; a long iron rod, passed through the barrel, projects at each end, and forms handles and also an axis on which the barrel rotates, more or less freely, according to the degree of pressure against the board. By moving it regularly sideways, the whole surface is ground over, and although the stones are well supplied with water, the sparks fly off with the brilliancy of fire-works. Many barrels, after being smoothed up, are finished in this way, the appearance of regularity being given to them at the muzzle by filing. The best barrels, however, are first set perfectly straight, then fixed on a movable carriage, which is drawn gradually forward along a level surface or railway, by means of a weight and pulleys, the boring-bit being fixed in a square hole in the axis of a revolving fly-wheel, while the barrel slowly advances until the bit passes out at the opposite end to that at which it entered. The same square bit is used to enlarge the bore to the required size by the addition of a spill, or long thin piece of wood, slightly taper, flat on one side and round on the other: this being placed along one side of the bit causes it to cut on two angles only, and the size of the calibre may be very gradually increased by interposing strips of writing-paper between the spill and the bit. Mr. Wilkinson states that "the best and most usual form for the inside of a barrel intended to throw shot, is a cylinder slightly relieved, or enlarged a few inches at the breech end: long barrels for duck-shooting should be eased gradually towards the muzzle end also. It is evident, that a barrel much opened behind must recoil more, and *lead* sooner, than one approaching nearer to a cylinder; and if resistance be necessary, it should be given to the powder, and not to the shot, which is accomplished by the elliptical form of breeching." When the barrel has been correctly bored, the external part is turned in a lathe, a steel mandril is introduced at each end, and the superfluous metal taken off by hand or by a slide rest. The barrel being rendered perfectly correct and equal in every part, is *tapped* or screwed at the breech end, and the plug fitted. It is next proved according to a scale fixed by Act of Parliament, with a charge of powder proportioned to the weight of a leaden ball that fits the bore.

The proving of guns is a very necessary precaution, to prevent, as far as possible, fraudulent makers from sending into the market barrels made of bad or unsound materials. In 1813, the Company of Gunmakers of the City of London instituted a proof-house, and obtained an Act of Incorporation: in 1815, further powers were granted to them, by which parties receiving any barrel to rib, stock, &c. without its having been first proved and stamped, are liable to a penalty of 20*l*., or not less than 20*s*. A similar establishment was also instituted at Birmingham, of which the following notice, with a few additional particulars, is from the second volume of the Editor's work on the "Useful Arts and Manufactures of Great Britain:"—

The Birmingham Company has also its Act of Incorporation, and wardens and a proof-master are appointed chiefly from among the gunmakers themselves, who are authorized to stamp on the guns proved by them the royal arms, with the letters B. P. V., that is, Birmingham Proof Viewed. The barrels of guns intended for the public service are proved at a separate establishment maintained entirely by the Government.

The Birmingham Proof-house is situated in Banbury street, in the south-east division of the town. The building is somewhat extensive, and is separated into several distinct compartments. Within an inner court-yard is the gunpowder magazine, a small but massive stone building standing by itself: beyond this is a room for casting bullets; they are cast in long moulds formed of two parts, containing, when closed, a series of hollow spheres connected by a long channel, along which the melted lead flows, and shorter channels into each sphere, so that the bullets are turned out in the form shown in Fig 1114, and are separated from the pipe and stems by a pair of nippers, with cutting edges, adapted to the surface of the bullet. Another department is appropriated to loading the barrels with powder and ball. The charge is regulated according to the weight and calibre of the barrel, a scale of printed regulations for the purpose being fixed up in the room. A measure filled with the gunpowder, containing three or four times the quantity which the barrel will afterwards have to bear, is poured in by means of a funnel, and well rammed down with a heavy copper ramrod; then the bullet, which exactly fits the barrel, is driven home, no wadding being used. A number of barrels being thus prepared, are taken to the firing-house, which is a low detached shed, lined throughout with thick sheet iron, and furnished with openings on one side and in the roof, which are closed with iron louvres. Iron frames are laid the whole length of the room for the reception of the barrels, to the number of 120, in two rows, one above the other. They are placed about 6 inches apart, and point to the opposite dead wall, against which is a mass of sand for receiving the balls. Behind the frame on which the twist barrels are fixed, is another mass of sand, in which, on the recoil, the barrels become buried. Behind the frame on which the common barrels and muskets are tried, a strong iron bar is placed, to receive the tang of the breech, but not the barrel, and thus fixed, the barrels cannot fly back. A groove runs along the whole length of each frame for the train of powder, and upon this are laid the barrels with the touch-holes downwards. Matters being thus arranged, the shutters are closed, the

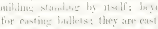

Fig. 1114.

doors locked, and a man with a long rod heated at one end fires the train through a hole in one of the end walls left for the purpose. The noise of the explosion is very remarkable, forming as it does a rapid succession of loud sharp reports, lasting a second or two, and resembling the rattle of thunder. This is easily to be accounted for; for however rapid may be the explosion of gunpowder, the fire has to travel the whole length of the train, in order to fire the guns; the time occupied herein occasions each gun to give a distinct report, which, being instantly followed by the report of the next gun, produces the rattle or continuous peal referred to. The explosion being ended, a few minutes are allowed to elapse before the men enter to remove the guns, because a barrel occasionally *hangs fire*, and may explode in the act of being removed. The shutters being thrown up, and the doors opened, the smoke rushes out in clouds, and the appearance of the barrels is not a little extraordinary. It is scarcely to be supposed that in so large a number some should not be faulty; the defects are so well known as to obtain for them their appropriate names. A few may have a *chink* or small rent in the direction of the length of the barrel; others may have a *crack* across it; while others again may have a *flaw*, which is a small pit or hollow in the metal. In any one of these cases the barrel is likely to burst in proving, and is whirled out of the frame to a distant part of the shed. The editor has collected some of the forms of the burst barrels in the following sketches. In examining a large number of them at the proof-house, he was surprised to notice several perforated as if with a bullet in the very act of proving; and such indeed they were. But how could this happen if the barrels are all ranged side by side? It has been already stated that an appreciable amount of time is occupied in the firing of a row of guns, and that when a barrel bursts, it is whirled by the force of the expanding gases out of its frame to a distant part of the shed. Now let us suppose that sixty barrels are arranged in one row, and fired by a train, and that the fifth in the row should burst, and be whirled out of its frame; in its passage to a distant part of the shed, it may meet the shot of one of the guns in advance of the position which it occupied in the row, in the very act of firing; such, for example, as the fortieth or fiftieth gun; and as this shot is urged by a triple or quadruple charge of powder, it would easily pass through the metal if it struck it favourably.

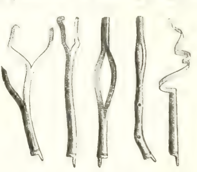

Fig. 1115.—GUN BARRELS BURST IN PROVING.

It rarely happens the best barrels burst: they are more frequently bulged or swelled out in places which are faulty, or of softer temper. The perfect barrels are marked with punches of different sizes, (but all bearing the same impression,) according to the quality of the barrel. At the London Proof-house, an additional punch is used, containing the number of the bore the barrel has been tried by, so that it can easily be ascertained whether the barrel has had any considerable quantity bored out after proving. The bulged-out barrels are sent back to the maker, who beats down the swellings, and sends back the barrel to be proved again. It will generally stand the second proof; but Mr. Greener has known four proofs of the same barrel to have been made. The common barrels are left untouched for four-and-twenty hours, when, if not burst, any holes or other imperfections are made quite apparent by the action of the saltpetre: such are sent back to the maker unmarked, but the sound barrels are washed out in a trough with warm water, and dried with tow. The viewer then carefully examines them, and hands such as are sound to the stamper, who attaches the proof-mark.

At the Government Proof-house at the time of the writer's visit, some barrels were being charged with 16 drachms of powder (only 4½ drachms being required for the gun in ordinary service); a wine-cork exactly fitting the barrel was then rammed down tight with a massive copper rod; the bullet was then put in, and another cork rammed upon that. Then each barrel was proved separately; for which purpose it was placed in a massive wooden chest, one end of which was left open for the escape of the bullet, which was fired as before into a pile of earth and sand. On closing the cover of this chest (which was nearly balanced by weights passing over a pulley), a spring was detached, which fired a percussion-cap and exploded the gun. In case of fracture, the chest protects the man from injury.

In some cases, the barrels are subjected to even a more severe test than either of the above. The barrel is filled with water, and an air-tight bullet driven in. Water being nearly incompressible, but transmitting pressure in all directions, insinuates itself into the minutest chink or crack, and appears on the outside, thus showing where the barrel is defective.

When false breeched, ribbed, stocked, and screwed together, the barrel is bored for shooting, and smoothed outside. Double barrels have a flat struck along the inner side of each before laying them together; about 4 inches of the breech end is braized or hard-soldered, the remainder of the length soft-soldered, the upper and under ribs being soldered on at the same time.

The lock and the barrel being jointed to each other if required, are given to the stocker, who lets them into the wood, which ought to be perfectly seasoned. The screwer-together lets in all the furniture, and puts in all the screws. The gun is detonated by another man, who fits the cock, and finishes the external part of the breeching. When the barrel has been smoothed and bored for shooting, the gun is returned to the screwer-together, or to another workman to *make off* and chequer; that is, to smooth and finish the wood-work. From him it passes to the *skipper* and *finisher*, who takes the whole to pieces, and corrects any trifling errors of the preceding workmen. The barrel is engraved and goes into brown; an operation performed by producing successive coatings of rust on the surface, and brushing them off as they arise with a fine steel wire *scratch-brush*, until the required colour is produced. This usually takes a week, and is effected by a solution of salts combined with nitric ether.[1] During this process, the lock and furniture are polished, engraved, blued, and hardened; and the stock is oiled and polished. The hardening is performed by burying the parts in animal charcoal, and keeping them at a red heat for an hour or more, and then plunging the whole into water. The whole of the parts are then returned to the finisher, and the gun is completed.

The stocks of all military fire-arms and most fowling-pieces are of walnut, which is the toughest and best wood for the purpose; but maple and ash are also used for sporting guns. All gun-stocks are coloured with cold-drawn linseed oil and alkanet root; and when sufficiently dry, those for the best guns are polished and varnished with shell-lac in spirits of wine, applied with a piece of rag, and when dry, rubbed down with fine pumice powder, and repeatedly varnished until all the pores of the wood are filled; and they are finally polished up with oil and rotten-stone, by hand.

Success in shooting depends a good deal on the proper adjustment of the stock to the stature of the shooter, or to his acquired habits. As a general rule, the taller a man is, the longer and more crooked ought to be his stock. The stock must also have an inclination outwards, to allow for the swell of the chest, as the eye cannot, without difficulty, be placed correctly in a line with the centre of the shoulder; hence, most persons shoot to the left of the object aimed at, particularly if the centre of the stock be in a right line with the barrel, or be *thrown off*, as it is called, the wrong way. The broader the chest, the more ought the stock to be inclined, or bent outwards sideways, and the extent is ascertained by observing the line of the barrel when the gun is thrown up to the shoulder at any distant fixed object.

Machinery for stocking military guns has been proposed and adopted to a considerable extent in France and America, and we have lately seen it applied in England.

The term *rifle* or *rifled* is applied to muskets or pieces of ordnance when their bores are furrowed with spiral grooves, the object of which will be understood from the following considerations. "A bullet made of lead cast in a spherical form, having unavoidably some irregularities on its surface, and from unequal expansion in cooling, a void space being formed in the interior, by which the density is caused to vary in different directions from the centre, it follows, that when such bullet is discharged from a common musket, the atmosphere pressing unequally against its front on opposite sides of the line of flight, causes it to deviate continually from the direction which, when uniformly resisted, it would take by gravity, and the impulse of the fired gunpowder. It will also happen that the bullet acquires by friction in the barrel a rotatory motion, about some diameter as an axis, and this diameter not coinciding, except by an extraordinary chance, with the proper path of the ball, the pressure of the air, which, when that coincidence does not take place, will be greater on the side of the ball where the revolving motion conspires with the direct motion, than on the opposite side, where the two motions are in contrary directions, will, even if there were no irregularity of surface, produce deviation. This will evidently be various, according to the position of the axis of rotation; and since that position may change during the flight of the ball, the path of the latter may suffer several inflections. The intention, therefore, of forming spiral grooves within the barrel, is to produce a rotatory motion of the shot about an axis which shall coincide with the line of its path, in order that the unequal pressure of the atmosphere in its front, on account of any irregularity in its form or density, may correct itself at every half revolution of the shot on such axis; so that, on arriving at the object, the deviation may be only that which is due to some fraction of a rotation. The number of spiral channels in a rifle musket has varied at different times; at first, there were 8 or 16, but the number was afterwards reduced to 4, and at present, the practice is to have but two. It has not been exactly determined what is the best form for the spiral; sometimes the curve-line makes in the length of the barrel 1½ revolution about the axis of the latter, but in general, one revolution in the whole length (= 30 inches) is considered sufficient."[2]

GUN COTTON. Ordinary cotton is one of the innumerable forms of lignine, a compound of carbon, oxygen, and hydrogen; but by subjecting cotton to the action of nitric acid, another element enters into the composition, viz. nitrogen, which is found in nearly all explosive bodies. The action of nitric acid on vegetable matter had long attracted the attention of chemists before the discovery of the remarkable explosive compound which we are about to notice. In 1833 Braconnet gave an account in the *Annales de Chimie*, &c. of a new substance obtained by the action of concentrated nitric acid on starch, saw-dust, linen and cotton wool. He named this substance *xyloidine*, from *ξύλον, wood*, and described it as being white, pulverulent, neutral, and very inflammable. It

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(1) Mr. Wilkinson gives the following recipe:—Nitric ether 6 oz., alcohol 1 oz., sulphate of copper 1½ oz., muriated tincture of iron 1½ oz., tincture of gum benzoin 1½ oz. The sulphate of copper must be dissolved in 3 pints of boiling water, and the other ingredients, previously mixed together, added

(2) "Penny Cyclopædia," art. Rifle.

is easily formed by boiling starch for a few moments in concentrated nitric acid until solution takes place; on pouring the solution into cold water, the xyloidine is precipitated, and may be collected and dried. In 1838 Pelouze, in the *Comptes Rendus*, called the attention of the Academy of Sciences to the properties of xyloidine, "which," he observes, "is very combustible, taking fire at 356° Fahr., burning with great rapidity and almost without residue. This property has led me to an experiment which I think susceptible of some applications, especially in artillery. By plunging paper in nitric acid of sp. gr. 1·5, leaving it there the requisite time for the acid to permeate the paper, which is usually accomplished in 2 or 3 minutes, then withdrawing it, and lastly, washing it in water, we obtain a kind of parchment impermeable to moisture, and extremely combustible." Dumas in the sixth vol. of his "Traité de Chimie appliquée aux Arts," published in 1843, proposed to name the compound *nitramidine*, and mentions the application of paper and pasteboard prepared by nitric acid for fireworks. At a meeting of the British Association at Southampton, in 1846, it was announced that Professor Schönbein had discovered a mode of rendering cotton so explosive as to form an excellent substitute for gunpowder. Specimens of the prepared cotton were exhibited, but the method of preparation was kept secret, as the inventor was then applying for a patent. Soon after this announcement Professor Otto, of Brunswick, published an account of an explosive cotton, as did also M. Morel, of Paris, and M. Böttger, of Frankfort. In April, 1847, Schönbein's patent was enrolled: the specification states that in preparing the cotton the patentee uses nitric acid of sp. gr. 1·45 to 1·50, and sulphuric acid of sp. gr. 1·85. These acids are to be mixed in the proportion of 3 parts of sulphuric and 1 part of nitric acid: the mixture is allowed to cool down to between 50° and 60° Fahr., and then rough cotton, free from all extraneous matter, is immersed in the liquid, in as open a state as possible, in a glazed earthenware vessel. When thoroughly soaked, the excess of acid is to be drawn or poured off and the cotton pressed lightly with an earthen presser to separate the principal part of the acid. The cotton is then covered over and left for an hour, then pressed, and well washed in running water, to get rid of all free acid: it is then to be partially dried by pressure, and to ensure its freedom from acid it is to be washed in a dilute solution of carbonate of potash, made by dissolving 1 oz. of this salt in a gallon of water: it is then put in a press, and the excess of alkaline solution pressed out, leaving the cotton nearly dry. It is next washed in a solution consisting of 1 oz. of pure nitrate of potash in 1 gallon of water, and when again pressed is dried in a room heated by steam or hot water to the temperature of from 150° to 170° Fahr. The nitrate of potash appears to increase the explosive force of the cotton, but it is not absolutely necessary. Of the cotton thus prepared 3 parts are said to be equal in force to 8 parts of Tower-proof gunpowder.

A simpler method of preparing gun cotton in small quantities was proposed by Mr. Thomas Taylor in October 1846:—"Mix in any convenient glass vessel an ounce and a half, by measure, of nitric acid, (sp. gr. 1·45 to 1·50,) with an equal quantity of sulphuric acid, (sp. gr. 1·80.) When the mixture has cooled, place 100 grains of fine cotton wool in a Wedgwood mortar, pour the acid over it, and with a glass rod imbue the cotton as quickly as possible with the acid. As soon as the cotton is completely saturated, pour off the acid, and with the aid of a pestle, quickly squeeze out as much of the acid as possible. Throw the mass into a basinful of water, and thoroughly wash it, either in successive portions of water or underneath a tap, until the cotton has not the slightest acid taste. Finally, squeeze it in a linen cloth, and dry it in a water bath." Nitric acid of the sp. gr. 1·50 answers better than that of 1·45, the cotton being much less acted upon by the strong acid. Nitric acid of the sp. gr. 1·36 converts the cotton into a gelatinous mass.

Gun cotton is considerably heavier than unprepared cotton, and may be distinguished therefrom by its harshness, and by the crepitating sound produced when pressed by the hand. When well prepared, there is scarcely any change in colour or in general appearance. It may also be distinguished from common cotton by its electric condition, for if a portion be pulled briskly between the finger and thumb of a dry hand, the fibres will adhere to the hand with great tenacity. If a strip of prepared paper be thus treated, it will, on presenting one end to the knuckle, be alternately attracted and repelled, and thus part with its electricity. Gun cotton is also perfectly soluble in sulphuric ether, and if the solution be poured on the surface of cold water, the xyloidine forms an opaque film thereon, which when collected and dried forms a remarkable explosive paper. The etherial solution of gun cotton (named *collodium*) applied to a wound, coats it with a thin, delicate, artificial skin, which perfectly excludes the air.

The explosive character of gun cotton appears to be due to the formation of xyloidine in the tubes and upon the exterior of the cotton fibre under the action of the nitric acid. The sulphuric acid employed has no direct action on the lignine, its use being to abstract water, and thus render the action of the nitric acid more perfect. Gun cotton explodes with very great rapidity at from 350° to 400° Fahr. If a small heap of gunpowder be placed on a sheet of writing paper, and a bit of gun cotton be laid lightly upon it, and the whole held about a foot above the flame of a lamp or candle, the heat will soon be sufficient to ignite the cotton, but the powder will not be kindled, and although the cotton explodes in contact with the powder, its action is so rapid that there is not time enough to raise the gunpowder to the temperature required for its explosion. "This great rapidity of action is opposed to its utility for propulsive purposes. It is well known to practical men that a slowly exploding material is the best for artillery practice. Thus, when a slow powder is used, the ball acquires a slight degree of motion, and puts the air in front of it in motion also, before the full power of the explosion is exerted; and that motion is gradually increased during the remainder of the explosion. But if the action takes place too quickly, the full force of the propelling power comes into play before the ball is in motion, and the bursting of the gun is the probable consequence. This is the reason why the fulminates of mercury and of silver have not been more extensively used in warfare. When gun cotton has been carefully prepared, the products of its combustion are carbonic acid, watery vapour or steam, and free nitrogen. In some cases nitrous acid is produced, owing to defective washing, and when nitrate of potash has been employed, or, in fact, a solution of any solid salts, a dense white vapour accompanies the explosion. The quantity of water produced during the decomposition of the cotton by heat is so great, as to constitute an objection to its use in fire-arms. Its hygrometric condition also impedes its utility; for if a quantity be exposed for an hour or two to a damp atmosphere, it absorbs nearly its own weight of water, and requires re-drying before it can be used; it cannot be protected from atmospheric moisture by compression into cartridges, as in that state it does not explode with certainty. The idea of employing the fulminating cotton as a substitute for gunpowder for artillery purposes seems to be completely abandoned; but on account of the small quantity of smoke given off, as well as on account of its enormous force, it is much used for mining purposes; the proportionate quantity used being a fourth of that of powder."[1]

The expense of gun cotton is considerably greater than that of gunpowder, one reason for which is the difficulty and danger of manufacturing it in large quantities: it is also liable to spontaneous ignition or decomposition by keeping: Maurey describes a fearful spontaneous explosion of 1,600 kilogrammes of gun cotton, which had been washed with alkaline water. The explosion took place in his manufactory in July 1848, and he is not aware of any method of guarding against such accidents. Hence the use of gun cotton has been gradually abandoned in mining, and this substance, which a few years ago excited such great expectations, now scarcely occupies a rank higher than that of the curiosities of chemical science. [See APPENDIX.]

GUN FLINT. See FLINT.

GUNPOWDER. The Chinese appear to have been acquainted with gunpowder 200 years before the Christian era, if not earlier, and to have used it in their fire-works, and for purposes of deflagration, but not for detonation, or the propulsion of solid bodies. Such a compound as this is supposed to have been obtained by the Arabs, in their intercourse with China, and by them communicated to the Greeks of the Lower Empire, and to have formed the celebrated *Greek fire*, which enabled those who possessed the secret of its composition to gain so many victories; at any rate, the machines of war used by the Greeks at the period referred to are said to resemble those of the Chinese so closely as to lead to the suspicion of a common origin. Various recipes for deflagrating compounds are given by Marcus Græcus in his "Liber Ignium ad Comburendos Hostes," but no more precise date than between the 9th and 12th centuries has been assigned to this composition.[2] The crusaders in their early conflicts appear to have been struck with terror at the incendiary weapons used against them; and it has been conjectured, that to them do we owe the introduction of a form of gunpowder into Europe. It is probable that the impurity of the saltpetre and the imperfect method of mixing the ingredients, prevented the Chinese, Arabs and Greeks, from using gunpowder as a propelling force, and that the same proportions of saltpetre, charcoal, and sulphur, which give us a detonating compound, gave them only a deflagrating one. The alchemists may so far have supplied these defects as to have earned for them the merit of the invention. Such may have been the case with Berthold Schwartz, a Franciscan friar, who lived at Mayence between 1290 and 1320, whom the Germans claim as the inventor of gunpowder.

Referring the historical portion of our subject, which is beset with difficulties, to those who are competent to discuss it,[3] we would call attention for a moment to the great importance of the discovery of gunpowder, in assisting the progress of civilization. Its first effect was to change entirely the whole system of warfare, whether offensive or defensive: the feudal lord, who could no longer feel secure in his stronghold, which the cannon planted on the adjacent heights might batter about his ears, ceased to be tyrannical, and was gradually led to the belief that his own interests might be identical with those who practised vulgar arts, instead of the knightly profession of arms. The use of gunpowder in battle rendered wars less bloody, by keeping the combatants at a distance from each other: the modern improvements which are being made in fire-arms will have the effect of increasing that distance, and thus gradually rendering war impossible; for if the rifle be made to kill with certainty at the distance of 1,000 yards, the soldiers will refuse to appear within sight of it; and if a small arm can be made to discharge a bullet five-and-twenty times in a minute, charges of cavalry will be impossible; so that unless war be reduced to a succession of surprises, it would scarcely admit of being carried on in pitched battles. Governments

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(1) Dr Ryan in the "Aide-Memoire to the Military Sciences," vol ii part 1 1848.

(2) The recipes given by Albertus Magnus and Roger Bacon were probably derived from this work. Bacon (who died in 1278) conceals one of the ingredients under the veil of an anagram. He writes, "Sed tamen salis petrae, *luru mone cap ubre*, et sulphuris, et sic facies tonitrum et coruscationem, si scias artificium." The italics are unmeaning in their present form, but the letters will make *carbonum pulvere*, or powdered charcoal. The passage may then be translated thus:—"But nevertheless, take of saltpetre, with powdered charcoal and sulphur, and thus you will make thunder and lightning, if you know the mode of preparing it."

(3) See an essay "Sur le Feu Gregeois et sur la Poudre a Canon," by M Lalanne, noticed in the "Annales de Chimie et de Physique" for 1842. Also a notice of the researches of MM. Reinaud and Favé, in the same work, for 1846.

would therefore be obliged to dispense with the costly luxury, reserve their big guns to announce the birth of princes, or to welcome with complimentary thunder the approach of great ones. Gunpowder will probably continue to present an available store of mechanical force to the miner and the engineer: the sportsman will still continue to use it in securing his game, and to the fire-work maker it will ever form a necessary article.

The great importance attached to gunpowder by different nations has displayed itself in a remarkable manner, for without any knowledge of the law of definite proportions, and even before the existence of true chemistry, and probably without any communication with each other, each nation has long been in the habit of using very nearly the best proportions of the 3 ingredients, viz. 1 equivalent of nitre, 1 of sulphur, and 3 of charcoal, or 75 per cent. of nitre, 11·77 of sulphur, and 13·23 of charcoal. The following statement shows the composition of different gunpowders:—

	Nitre	Charcoal	Sulphur
Royal Mills, at Waltham Abbey	75	... 15	... 10
France, National Establishment	75	... 12·5	... 12·5
French, for Sportsmen	76·9	... 13·5	... 9·6
French, for Mining	62	... 18	... 20
United States of America	75	... 12·5	... 12·5
Prussia	75	... 13·5	... 11·5
Russia	73·78	... 13·59	... 12·63
Austria (Musket)	72	... 17	... 16
Spain	76·47	... 10·78	... 12·75
Sweden	76	... 15	... 9
Switzerland (round powder)	76	14	... 10
Chinese	75·7	... 14·4	... 9·9

In practice the ingredients used in the manufacture of every 100 lbs. of gunpowder are, saltpetre 77½ lbs., sulphur 10½ lbs., charcoal 16 lbs.=104 lbs., the extra 4 lbs. being allowed for waste.

The saltpetre as imported is unfit for the manufacture of gunpowder, as it is combined with common salt, or with salts such as nitrate of lime, which absorb moisture, and prevent the close contact and combination of the other ingredients. The loss which rough nitre sustains in refining is termed the *refraction*. It is refined by solution in an equal weight of spring or river water, which is quickly raised to a boiling heat, and after four or five hours allowed to cool; it is filtered through canvass bags, and crystallized in copper pans. The nitre is then purified a second time in a similar manner, but with a smaller quantity of water, 10 parts water being used to 14 of nitre: after the second crystallization, the water in the crystals is expelled by fusion, and the nitre assumes a delicate white appearance. The principle of this purification is founded on the greater solubility of nitre in hot than in cold water: 100 parts of water dissolve 236 parts at 207°, and only 29 at 64°; while nitrate of lime being a deliquescent salt is retained in the menstruum after the nitre has been separated by crystallization.

The sulphur is purified by a double process of fusion in gun-metal pots by a gentle heat for about four hours.

The value of gunpowder greatly depends on the quality of the charcoal. It is found to be less contaminated with foreign matters when prepared in iron cylinders, instead of charcoal-pits: the best woods for the purpose being the black dog-wood, the alder, and the Dutch white willow. It is best when newly made from seasoned wood; it should be perfectly charred, and exhibit throughout its section the same appearance, either dead black, or shining, according to the nature of the wood: it should be soft, and free from extraneous particles, so as not to scratch polished metal: it should give out no smoke when in a state of ignition, and yield no alkali to boiling distilled water. It should be stored in small quantities of 2 or 3 cwt., because in a large mass it is liable to spontaneous combustion.

The three ingredients being reduced to an impalpable powder, are mixed together in a barrel in the proportions already indicated, in which state they are conveyed to the incorporating cylinder mill in charges of 42 lbs.; each charge is moistened with 2 or 3 pints of water, according to the temperature, or hygrometric condition of the atmosphere. In this mill the runners or cylinders are 6 feet in diameter, and about 18 inches thick, weighing about 3 tons each: the circular bed in which they travel is about 7 feet in diameter: they cannot with safety be allowed to revolve more than 8 times per minute. Both runners and beds were commonly made of compact limestone or marble, but it has been found that cast-iron can be used without danger, provided the gudgeons work in gun-metal. Each charge requires to be 3½ hours in process of incorporation, so that this period regulates the quantity of gunpowder which can be manufactured at one incorporating mill. Major-General Fanshawe suggests, "whether by a greater degree of manipulation in the mixing tub, a shorter time for each charge would not suffice under the cylinders of the incorporating mill, and thus produce, without compromising the thoroughly close and compact combination of the elementary particles, a much greater quantity of gunpowder in a given time."[1]

The thorough incorporation of the ingredients is most essential to the production of good gunpowder. Considerable experience is necessary to direct the operation, and decide upon the fitness of the mixture, which at the end of the process should have a uniform grey appearance. The mixture, now called *mill-cake*, is next subjected to a pressure of about 75 tons per superficial foot, in a hydrostatic press, for which purpose mill-cake powder is placed on the bed or follower of the press, and separated at equal distances by sheets of copper, so that when taken out it is in the form of large thin solid cakes, termed *press-cake*. This is crushed between toothed rollers of different successive guages, or broken by wooden mallets into small pieces, which are put into parchment sieves pierced with holes of the size required for the particular kind of gunpowder which is being manufactured. The sieves are mounted in a frame suspended at the corners, to which a shaking motion is given. Each sieve contains two flattened spheroids of lignum-vitæ, which, by the motion given to the

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(1) Aide Mémoire to the Military Sciences, art. *Gunpowder*.

frame, continue to crush the powder until it is reduced small enough to pass through the holes of the sieve. The gunpowder is received into hair-cloth sieves, which retain the *grained* powder and allow the dust to pass through.

The next operation is *glazing*, for which purpose the gunpowder is put into a canvas cylinder, or large cask, which is made to perform 40 revolutions per minute, and by the rubbing of the grains against each other the angular points are broken off, and the grains acquire roundness, as well as smoothness and polish of surface. The latter quality is sometimes fraudulently imparted by putting a small quantity of finely powdered black-lead into the glazing barrel.

The processes of pressing and glazing are of great importance, the one for imparting an equal degree of density to the grains, and the other a polish to their surface, by which the powder is less disposed to absorb moisture, and stands the shaking and friction of carriage better.

The last operation is to dry the powder thoroughly at the temperature of 140° or 150° Fahr. The old method of drying was by means of a *gloom-stove*, consisting of a large cast-iron vessel protruded through the wall into the drying-room, and heated by fire on the other side. The present method, which is greatly to be preferred, is to raise the temperature of the drying-room by means of steam-pipes, or to transmit a current of air previously heated in another chamber, over canvas shelves containing the damp powder.

The force of the explosion of gunpowder depends on the sudden conversion of the solid grains into gas, and the production of intense heat resulting from the action of the combustibles upon the nitre. The chief gaseous results are carbonic oxide, carbonic acid, nitrogen, and sulphurous acid; and the solid residue consists of carbonate and sulphate of potash, sulphuret of potassium, and charcoal. The maximum gaseous volume is produced by the formation of carbonic oxide and sulphurous acid with the liberation of nitrogen. With 1 equivalent of nitre, 1 of sulphur, and 3 of charcoal, the nitre yields 5 proportionals of oxygen, of which 3, combining with 3 of charcoal, furnish 3 of carbonic oxide gas, and the remaining 2 convert 1 of sulphur into sulphurous acid gas, and the single proportional of nitrogen is disengaged alone. Hence the gaseous volume produced by 130 grains of gunpowder, equal in bulk to 75·5 grains of water, or $\frac{3}{10}$ of a cubic inch, will, at the atmospheric temperature, be as follows:—

	Grains.	Cubic inches.
Carbonic oxide	42	141·6
Sulphurous acid	32	47·2
Nitrogen	14	47·4
		236·2

being an expansion of 1 volume into 787·3. But as the temperature of the gases at the moment of formation must be incandescent, this volume may be estimated at 3 times the above amount, or considerably more than 2,000 times the bulk of the solid.

This theoretical account does not, however, quite agree with the products obtained by experiment, especially as regards the evolution of carbonic acid and the residuary sulphuret of potassium. Professor Graham has therefore given the following view of the results of the deflagration as being more consistent with experiment:—

Before combustion.		After combustion.
3 equivalents of Carbon		3 Carbonic acid.
	6 Oxygen	
1 equivalent of Nitre	1 Nitrogen	1 Nitrogen.
	1 potassium	1 Sulphuret of potassium.
1 „ Sulphur		

Carburetted and sulphuretted hydrogen and vapour of water are sometimes found among the products of the combustion of gunpowder: but as good gunpowder does not contain more than 1 per cent of water to furnish the hydrogen, the quantities must be very minute. Gunpowder burns under water, so that by using a slowly-burning powder, such as is used for filling squibs, inflamed in a copper tube, the gaseous products may be collected over water in the pneumatic trough. The port-fires used by the artillery answer very well for the purpose; but in these, not only is a slow burning powder used, but the combustion is delayed by distributing the powder through a great length, and subjecting it to strong compression.

The chief use of the sulphur in gunpowder is to increase its combustibility in consequence of the low temperature at which it burns: but the larger the proportion of the sulphur, the weaker will be the gunpowder. Thus, a powder containing 12 per cent. of sulphur and 12 of charcoal, does not throw a proof shell so far as a powder containing 19 of charcoal and 9 of sulphur; but the former powder is better adapted for keeping than the latter. The rapidity of the combustion, and consequently the force of the explosion, is increased by the granulation, because, by making the charge porous, the flame can penetrate it and kindle every grain in very rapid succession. The combustion of the press cake is very much more gradual.

The goodness of gunpowder may be tested by placing two heaps of about 60 grains each upon clean writing-paper 3 or 4 inches asunder, and firing one of them with a red-hot wire: if the flame ascend quickly with a good report, sending up a ring of white smoke, leaving the paper free from white specks, and not burnt into holes, and if no sparks fly off from it to set fire to the contiguous heap, the powder is very good: if these tests fail, the ingredients are badly mixed, or impure.

The strength of gunpowder is tested by measuring its projectile force by the *éprouvette*, which is a small strong barrel, in which a given quantity of powder is fired, and the force of expansion is measured by the action exerted on a strong spring, or a great weight. Another method is to fire a heavy ball from a short mortar, with a given weight of the powder, and to ascertain the range of projection. The éprouvette formerly used in France, was a mortar 7 French inches in calibre, which, with 3 ounces of powder, was to throw a copper globe weighing 60 lbs. to the distance of 300 feet.

Some of the effects of ignited gunpowder are truly astonishing. Count Rumford loaded a mortar with $\frac{1}{20}$th of an ounce of powder, and placed upon it a 24-pound cannon weighing 8,081 lbs.; he then closed up every opening as completely as possible, and fired the charge: the mortar burst with a tremendous explosion, and lifted up the enormous weight. In another experiment, he confined 28 grains of powder in a cylindrical space, which it just filled; and upon being fired, it tore asunder a piece of iron which would have resisted a strain of 400,000 lbs. [See APPENDIX.]

GUTTA PERCHA.[1] The concrete juice of a forest tree, native of the shores of the Straits of Malacca, Borneo, and the neighbouring countries. The natives had themselves discovered its valuable properties before they became known to Europeans. They constructed whips, buckets, and vessels of various kinds out of the hardened juice, and thus excited the attention of travellers to a substance which has since been applied to a vast variety of domestic and scientific purposes in this country. Their method of proceeding, however, has been of the most destructive kind, especially since the demand of the European market for this substance has had to be met. Instead of economising their treasure, as is done in the case of the caoutchouc, by tapping the tree and allowing its juice to ooze gradually from the incision, they fell the trees at once, and removing strips of bark at intervals, collect indeed a large quantity of sap at one time, but destroy all future supplies from that source. This wholesale destruction of the gutta trees, which are naturally slow of growth, must, if unchecked, necessarily involve the destruction of the traffic which is now so brisk and advantageous in this article. To put any check upon these proceedings is said, moreover, to be extremely difficult; because each set of explorers, in searching after these trees, is more anxious for present profit, than for future benefit to the trade. A very small quantity, comparatively speaking, is to be obtained by tapping, and it is evidently to the interest of the first comers to get a full supply of sap for themselves, without considering those who come after, and who might very probably cut down the trees if they had been spared previously.

The first accounts which reached us of these trees were given by Dr. Montgomerie, of Bengal, who appears to have been the first person to notice the native use of this substance: this was in 1842. In 1843, Dr. D'Almeida presented a specimen of their inspissated juice to the Royal Society of Arts, and described some of the advantages which would accrue from its use. This communication led to no results; but another, made shortly after by Dr. Montgomerie, was more successful, so that by the united efforts of these gentlemen gutta percha was introduced to public notice, and soon told its own tale to our manufacturers. They could not be blind to the advantages offered by a material possessing many of the properties of caoutchouc, with others in addition essentially its own. The abundance of the supply also encouraged invention, and in a very short time gutta percha was applied to multifarious uses, and became a valuable auxiliary in the arts.

The tree which produces this substance is from sixty to seventy feet high, and three or four feet in diameter. Its foliage is of a pale green on the upper side, and covered with reddish-brown hairs beneath. Specimens of the flowers and fruit are exceedingly difficult to be obtained. The tree flourishes luxuriantly in alluvial tracts, at the foot of hills, and forms in many places the principal part of the jungle in such situations.

From communications of Sir W. J. Hooker to the London Journal of Botany, it appears that numerous well-dried specimens of the gutta percha, though unfortunately without corollas, were sent to this country by Mr. Lobb during his botanical mission in the east, accompanied by sections of the wood, which is peculiarly soft, fibrous, and spongy, pale-coloured, and traversed by longitudinal receptacles or reservoirs, filled with the gum, forming ebony black lines. Application was then made to Dr. Oxley, of Singapore, for flowering specimens, and these were immediately supplied by him in the most obliging manner, and transmitted to England in a thin box, the top and bottom of which were made of sheets of the gum itself, (now deposited in the Museum of the Royal Gardens at Kew.) From the more accurate knowledge obtained by means of these specimens, Sir W. J. Hooker was able to refer the plant to Dr. Wright's new genus of Sapotaceæ, called Isonandra, and to name the plant *Isonandra gutta*. Fig. 1116 represents a branch of the *I. gutta*, and various portions of the

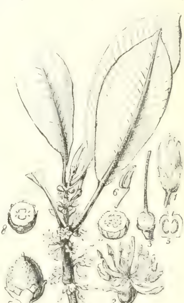

Fig. 1116. GUTTA PERCHA.

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[1] The word is a pure Malayan one, *gutta* meaning the gum or concrete juice of a plant, and *percha* the particular tree from which this is procured. The *ch* is not pronounced hard, like a *k*, but like the *ch* in the English word *perch*.—MONTGOMERIE.

blossom, as,—1, the flower scarcely expanded; 2, ditto, with the corolla expanded; 3, the pistil; 4, transverse section of the ovary; 5, vertical section of ditto; 6, the anther; 7, the scarcely matured fruit, natural size; 8, transverse section of the same.

After the natives have cut down the full-grown trees, they make rings in the bark at the distance of every ten or twelve inches, placing under each as they make it a cocoa-nut shell, or the spathe of a palm, as a receptacle for the milky sap which begins to flow immediately that the incision is made. The sap is collected in bamboos, taken to their houses, and boiled in order to drive off the watery particles, and inspissate it to the proper consistence. Boiling appears necessary when the juice is collected in large quantity, but when a small quantity is allowed to exude from a freshly wounded tree, and is collected and moulded by the hand, it consolidates perfectly in a few minutes, and has all the appearance of the prepared article.

Gutta percha when quite pure is greyish white, but it is generally brought to market of a reddish-brown hue. This is ascribed to chips of the bark, which fall into the sap and give it their colour, but in addition to this there are frequently other matters, such as saw-dust, purposely introduced as adulterants. Dr. Oxley, of Singapore, in an interesting description of this substance, first printed in a Singapore periodical in the year 1847, states that the tree which yields gutta percha was formerly very abundant on that island, but already all the large timber has been felled, and few but very small plants are to be found. "The range of its growth," he says, "appears to be considerable, it being found all up the Malayan peninsula, as far as Penang, where I have ascertained it to be abundant, although as yet the inhabitants do not seem to be aware of the fact, several of the mercantile houses there having sent down orders to Singapore for supplies of the article, when they have the means of supply close at hand. The tree is also found in Borneo, and I have little doubt is to be found in most of the islands adjacent." Respecting the wholesale destruction of the trees, the same writer observes,—"The quantity of gutta obtained from each tree varies from five to twenty catties, so that, taking the average at ten catties, which is a tolerably liberal one, it will require the destruction of ten trees to produce one picul. Now the quantity exported from Singapore to Great Britain and the continent from 1st January 1845, to July 1847, amounts to 6,918 piculs, to obtain which 69,180 trees must have been sacrificed. How much better would it, therefore, be to adopt the method of tapping the tree, practised by the Burmese in obtaining the caoutchouc from the *Ficus elastica*, (viz. to make incisions in the bark, placing bamboos to receive the sap, which runs out freely,) than to kill the goose in the manner they are at present doing. True, they would not at first get so much from a single tree, but the ultimate gain would be incalculable, particularly as the tree seems to be one of slow growth, by no means so rapid as the *Ficus elastica*. I should not be surprised, if the demand increases, and the present method of extermination be persisted in, to find a sudden cessation of the supply."

The great peculiarity which makes gutta percha convenient and valuable for a variety of purposes is, that when plunged into boiling water, it becomes so soft and plastic as to be easily moulded into any desired form, and this form it permanently retains on cooling. It was the discovery of this fact which first led the Malays to fabricate it into whips, and subsequently into basins, jugs, shoes, traces, &c. The medical profession soon became aware of its extreme value and applicability in the practice of surgery. Dr. Oxley early discovered it to be "the best and easiest application ever yet discovered in the management of fractures, combining ease and comfort to the patient, and very much lessening the trouble of the surgeon." He also employed it for bougies, capsules, tubes for syringes, &c.

Gutta percha tubing has been found extremely useful for water service, and for the conveyance of sound. Its extraordinary strength fits it for the former use in a remarkable degree. A series of interesting experiments were made two or three years ago at the Birmingham water-works, to ascertain the strength of tubes of $\frac{3}{4}$ inch diameter, and $\frac{1}{8}$ inch thickness. These were attached to the iron main, and subjected for two months to a pressure of two hundred feet head of water without being in any way deteriorated. In order to ascertain the maximum strength of the tubes, they were connected with the company's hydraulic proofing pump, the regular load of which is 250 lbs. on the square inch. At this point they were unaffected, and the pump was worked up to 337 lbs., but to the astonishment of every one the tubes still remained perfect. It was then proposed to work the pump up to 500, but it was found that the lever of the valve would bear no more weight. The utmost power of the hydraulic pump, therefore, was ineffectual to burst these tubes.

In the conduction of sound gutta percha is also found remarkably useful. Speaking tubes of this substance for the conveyance of messages are now fitted up in mines, railway stations, prisons, workhouses, hotels, and other large establishments. Partially deaf persons are found to appreciate its value: an ingenious apparatus for their use has been devised, including the distribution of the gutta percha tubing over a church or other large building, so that, by seating themselves at particular parts where these tubes terminate, such persons are able to hear distinctly the sermons or speeches delivered therein.

Gutta percha is also brought to the aid of the architect in the ornamental work of the interior of houses. It appears to be admirably adapted for cornices and centres for ceilings, also for picture-frames, and many other uses to which plaster and papier maché have hitherto been applied. It has likewise been employed for door handles and plates, for knife-handles, vases, baskets, &c., for the stopping of decayed teeth, and for printing in relief. The clear, sharp impression it receives, and the toughness of the substance, have made it very useful in books for the blind, and in maps embossed for their benefit. In solution this substance is employed in waterproof clothing; mixed with caoutchouc and other substances it is made into a light, porous, spongy material, suited for stuffing or forming the seats of chairs, cushions, and mattresses. Springs of clocks, clasps, belts, garters, and string, are prepared from a modification of the above mixture, while moulds and balls of gutta percha are produced of a hardness sufficient to bear turning in the lathe, like wood or ivory. A varnish may also be made in which gutta percha, being the principal ingredient, may be used to give a waterproof covering to other substances.

Gutta percha dissolves at ordinary temperatures, and still better at a higher heat, in sulphuret of carbon. The solution leaves behind on a glass plate a thin coating possessing all the properties of gutta percha unaltered. Pasteboard boxes coated over with this may be made to hold water.

Electrical experiments are aided by the use of gutta percha, for it has been found by Dr. Faraday to possess high insulating power. A letter from this distinguished philosopher, published in the "Philosophical Magazine," in March 1848, gives the following among other particulars:—"A good piece of gutta percha will insulate as well as an equal piece of shell-lac, whether it be in a form of a sheet, a rod, or filament, but being tough and flexible when cold, as well as soft when hot, it will serve better than shell-lac, in many cases where the brittleness of the latter is an inconvenience. Thus it makes very good handles for carriers of electricity in experiments on induction, not being liable to fracture; in the form of thin band or string, it makes an excellent insulating suspender; a piece of it in sheet makes a most convenient insulating basis for anything placed on it. It forms excellent insulating plugs for the stems of gold-leaf electrometers, when they pass through sheltering tubes, and larger plugs supply good insulating feet for extemporary electrial arrangements: cylinders of it, half an inch or more in diameter, have great stiffness, and form excellent insulating pillars. Because of its good insulation, it is also an excellent substance for the excitement of negative electricity. It is hardly possible to take one of the soles sold by the shoemakers out of paper, or into the hand, without exciting it to such a degree as to open the leaves of an electrometer one or more inches; or if it be unelectrified, the slightest passage over the hand or face, the clothes, or almost any other substance, gives it an electric state. Some of the gutta percha is sold in very thin sheets, resembling, in appearance, oiled silk; and if a strip of this be drawn through the fingers, it is so electric as to adhere to the hand or attract pieces of paper. The appearance is such as to suggest the making of a thicker sheet of the substance into a plate electrical machine for the production of negative electricity. Then as to inductive action through the substance, a sheet of it is soon converted into an excellent electrophorus; or it may be coated, and used in place of a Leyden jar, or in any of the many other forms of apparatus dependent on inductive action."

The properties thus noticed could hardly fail to bring this substance into use in telegraphic communication. Being flexible, impervious to water, and possessing insulating power, it is the most efficient of all substances as a coating or tubing for the copper wire of submarine telegraphs. Thus it aids in producing the most marvellous annihilation of time and space our age has yet witnessed. Gutta percha has been analysed by Dr. Maclagan, who obtained as its percentage composition, carbon 86·36; hydrogen 12·15; the remainder 1·49, was most probably oxygen absorbed from the air during the process of purifying it, as the substance whilst heating on the vapour bath acquired a brown colour.

Respecting the purification of gutta percha, Dr. Oxley gives a good hint to manufacturers when he says that gutta ought not to require an elaborate process: the simple boiling in water, and rolling out into sheets, whence all foreign matter can be easily picked off, is the only process he employs, and this he thinks would be generally sufficient, if manufacturers in giving their orders would take the precaution of requiring that the article should be strained through a cloth at the time of its collection, and if they would encourage the natives to do this, by offering a somewhat higher price for gutta percha so prepared. A vast deal of trouble and expense might, in his opinion, be saved in this way, and the various processes rendered unnecessary, which have from time to time been suggested for the purification of gutta percha.

The preparation of this substance for use is carried on on a large scale in the following manner. The lumps of gutta as they are received at the factory are first brought within the action of a vertical wheel, on the face of which are fixed three knives, which, as the wheel moves at the rate of two hundred revolutions per minute, rapidly cut the lumps into thin slices, discovering whatever adulterating materials may be contained therein. The gutta thus torn up is not uniform in colour or texture, but it is rendered so by the subsequent operations. It is first softened by soaking in hot water, (by which also the dirt and other impurities become separated from it,) and then thrown into a rotating machine, where it is dragged asunder by jagged teeth and reduced to fragments. These fragments fall into water, which still further tends to purify them, and are then softened into a paste in hot water, kneaded, and rolled between heated cylinders so that all parts may become thoroughly mixed and uniform. It may be then rolled out into sheets between steel rollers, or passed in the mass through heated iron cylinders, and made into tubes, or converted to the thousand purposes of ornament or use which we have briefly indicated. In the Great Exhibition gutta percha was seen in a vast variety of forms, but none were more interesting than those which illustrated the successive stages of its manufacture. The original lump, the slices, the shreds, the kneaded mass, the sheets ready for use; all appeared there. A very ingemous adaptation of the substance to making stereotype plates attracted much notice. A mould is taken by pressure of a page of type with woodcuts, in gutta percha; from this mould a cast is obtained on a cylinder of gutta percha, and from this last the printing is carried on. An hour, it is said, suffices to make both mould and cylinder.

GYPSUM is one of the varieties of native sulphate of lime, and is so named from γῆ, earth, and ἕψειν, to concoct; *i.e.* formed or concocted in the earth. The structure is fibrous and earthy. It is widely distributed throughout the world, and was well known to the ancients, who applied it to many of the same uses for which it is valued at the present day. In England it abounds in the London and other clays, but its great repository is in the rock commonly called new red sandstone. Numerous quarries exist in that formation, and those of Derbyshire, South Yorkshire and Nottinghamshire are in high repute. The better sorts of Derbyshire gypsum are employed in the Staffordshire potteries, as an ingredient in certain kinds of earthenware and porcelain, and also in making moulds for such articles of pottery as cannot be shaped on the common wheel. The finest pieces of this gypsum are reserved for ornamental purposes, such as vases, small statues, &c., of which a considerable manufacture exists in Derby. Gypsum in this form generally bears the name of *alabaster*,[1] and is remarkable for its softness, purity of colour, and fragile character: once soiled, its purity cannot be restored by ordinary washing, and it is also extremely liable to crack. Articles of delicate workmanship in this material are therefore preserved under glass. Alabaster abounds in the tertiary strata of Montmartre, near Paris, and sometimes it forms entire hills. In the Tyrolese, Swiss, and Italian Alps it is found upon the primitive rocks, often of the purest white, especially at Moutiers, near Mont Blanc, and near the summit of Mont Cenis.

There is also a crystallized or hydrous variety of gypsum ($CaO, SO_3, 2HO$). It is called *selenite*, from σελήνη, the moon, in reference to its soft lustre. The primitive form of selenite is a rhomboidal prism: the crystals are commonly transparent, of a sp. gr. 2·32, and of various colours, and it is so soft as to yield easily to the nail. These crystals are often disseminated in argillaceous strata, as at Alston in Cumberland, and at Shotover Hill in Oxfordshire, accompanied by shells and pyrites. These crystals are capable of division into thin plates, if split in a direction parallel to their two broad planes. This was known to the ancient Romans, who made use of these thin and semi-transparent plates instead of window-glass. A variety of gypsum, known as *lapis specularis*, furnished these laminæ of great size, sometimes five feet long. By this means, conservatories were glazed for the preservation of fruit-trees during winter, and beehives were made transparent, for the purpose, as Pliny states, of enabling the curious to see the working of those insects.

Fibrous gypsum, or satinstone, is much softer than alabaster, and is fashioned into necklaces, &c. of considerable beauty.

An *anhydrous* variety of gypsum, or one containing no water, is known to the mineralogist as *anhydrite*; it is harder and denser than selenite, its specific gravity being 2·96; it sometimes contains common salt, when it is called *muriacite*. It is generally massive and lamellar, rarely crystallized, but is susceptible of division into rectangular prisms. It has been found in Derbyshire and Nottinghamshire of a pale blue tint; sometimes it is pink or reddish, and often white. It is found at Vulpino, in Italy, and hence called *Vulpinite*. The artists of Bergamo and Milan employ it under the name of *Marbre di Bergamo*.

Gypsum, when calcined and reduced to powder, can be brought to a pulpy mass by admixture with water, and is the well known *Plaster of Paris*. This mass very soon sets, or returns to the solid form, giving out, while in the act of doing so, a considerable degree of heat. Advantage is taken of this fact in the use of gypsum as a material for casting and taking impressions. The writings of Theophrastus and other Greek authors show that this use of gypsum was known to them. They distinguished two kinds of gypsum, the pulverulent and the compact: the latter was obtained in lumps, which were burnt in furnaces, and then reduced to powder. This powder, mixed with water, formed a cement for buildings, and was also used for taking impressions. Casts were taken in gypsum from the living face: from the moulds thus formed other casts were taken in wax, that soft material allowing any imperfections which had occurred in the plaster casts to be rectified. Gypsum was also employed in stucco work for wreaths, medallions, and other ornaments of ceilings, cornices, &c.

The purest gypsum is required in making casts: the best part of the crystalline gypsum rocks of Newark is well adapted for that purpose. This should be quarried in dry weather, stacked under covered sheds, and conveyed to the place of manufacture in a perfectly dry state. Here it is sorted into two or three qualities, the central part of each block, which is the finest and best, being selected. The calcining ovens are heated with billet-wood, and the gypsum, previously reduced to small pieces, is thickly strewn on the floor of the oven to the depth of five or six inches. The door is then closed, and kept in that state for twelve hours, after which it is opened, but the gypsum is left for two or three hours longer. It is then placed in covered boxes for some hours, and finally ground between stones, and run through a lawn sieve. This process gives a gypsum fit for medal-casting, and other fine purposes. Gypsum in this powdered state may be preserved uninjured for any length of time, if perfectly excluded from the air, but as this is nearly impossible, it is better not to prepare a large quantity at one time. The quality of the powder may be tested by an experienced person, simply by squeezing it in the hand: if it cohere slightly, like wheat-flour,

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(1) There is some doubt as to the derivation of this word, but it is supposed to be from α, without, and λαβὴ, a handle, referring to a vase or box without handles, for containing perfumes.

it is good; but if it fall to pieces immediately, it has been injured by damp. In the baking of the gypsum care must be taken not to overheat it, or it will assume the crystalline character of *anhydrite*, and not set on the addition of water. The specific gravity of anhydrous sulphate of lime (artificial) is 2·927.

Considerable judgment and care are required in mixing the gypsum with water, and in giving the plaster just the proper degree of fluidity which will cause it to enter all the lines of the mould, and not that excess which would render the finished work porous and fragile. The powder must be shaken into the water by degrees, or better still, dropped in by hand, and distributed so that it may not collect in lumps, but become gradually and completely soaked. This should be continued till the powder comes to the level of the water, if for thin plaster, and until it stands slightly above it if a strong one is required. It is left undisturbed for a few seconds, and then gently stirred with a spatula until it thickens, when it is immediately poured into the mould. Good plaster should be of the consistence of cream, and will set or become solid in ten minutes, though it is not safe to remove the mould until half an hour has elapsed. The nature of the water used will affect the setting of the plaster, for it is found to set a few seconds earlier with river-water than with spring-water; hence, where large castings are to be performed, the first quantity is mixed in river-water, the second in spring-water, to allow the necessary time for applying them. There are modes well known to the workmen of hastening or retarding the setting; for the former, hot water or salt and water can be used; for the latter, a little size, beer, or urine, mixed with water, will retard it four or five hours. But all these expedients are objectionable, as injuring the quality of the plaster.

To prevent the plaster adhering, the mould, or original, is first smeared with oil, or if marble statues are to be operated on, which would be injured by oil, then a substitute is found in first brushing the surface with white of egg, and when this is dry applying a strong solution of soap in water mixed up with a little clay. Plaster casts may be hardened, and made to look somewhat like marble, by first drying them gradually at a moderate heat, and then coating them with melted white wax. The casts are then warmed at the fire until the wax is absorbed, when a translucent appearance is given to the cast, and a considerable polish may be obtained by friction.

In all objects presented in relief, it is obvious that in order to get a copy also in relief, a hollow mould must first be made on the original, and the plaster poured into this mould. In medal-casting these moulds are often made of sulphur, but this is perhaps inferior to white wax, which gives a very perfect impression of the medal. Into the mould thus formed, plaster is poured, at first thinly, and worked into all the cavities with a camel's-hair pencil, then more plaster is added, and the whole left for half an hour to harden.

Inferior kinds of gypsum are used for building material and for floors. For the former it is burnt in kilns on a large scale, and the cement made from it is mixed with sand as well as water. For floors, the same kind of gypsum, first dried at a very gentle heat, is pulverized, and then put by itself in an iron pot, and placed over the fire. The lower particles are soonest heated, and their water of crystallization, amounting to 21 per cent. of the whole, is converted into steam, which, escaping through the incumbent mass of powder, gives it an undulatory motion; hence this process is called *boiling*, although no liquid is used. When all the moisture is driven off, the motion ceases, and the gypsum is ready for use.

Many years ago Professor Emmet[1] showed that raw or native gypsum may be rendered capable of perfect solidification without having undergone the operation of burning. If the raw gypsum be finely pulverised, and mixed with a solution of caustic potash, of carbonate or bicarbonate of potash, sulphate, silicate, or double tartrate of the same alkali, it undergoes immediate and perfect solidification. The solid plaster thus formed does not appear to differ from the burnt plaster set in the ordinary way, except, of course, in chemical composition; and it is remarkable that the solid masses when broken up and worked with fresh portions of the solutions, recover their tendency to set, even though the operation be repeated three or four times.

There is a marked difference in the time required for the operation. Solutions of carbonate and sulphate of potash, if sufficiently dilute, produce their effects so slowly as to admit of complete incorporation; whereas Rochelle salt acts as soon as the powder touches the fluid, and all subsequent motion weakens the cohesion.

It is a remarkable fact that the addition of one or two per cent. of sulphate of potash, of alum, or of borax, delays the setting of plaster of Paris three or four hours, and converts it into a stone-like body of a higher specific gravity than the ordinary set plaster. The method of making the addition of one of the above salts is, to bake the lumps of gypsum, so as to deprive them of their water of crystallization, and to quench them in a solution of one of the above salts; then to bake again at a red heat, and afterwards grind to powder. On mixing this powder up with water in the usual way it will take three or four hours to set, and will form a hard dense solid. The addition of one of the above-named salts also prevents the gypsum from assuming a crystalline character by overheating, and even allows a much higher temperature to be used in the burning without injury.

The finest pure white compact gypsum, found near Derby, is the *alabaster*, of which we have already spoken. But this is inferior to the beautiful alabaster of Italy, which is also employed in sculpture. The Italian alabaster is semi-transparent when first raised from the quarry, and is wrought into the desired form while in this state; but it is then usually rendered more opaque by being entirely surrounded and

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(1) American Journal of Science and the Arts, vol. xxiii.

covered by cold water, which is gradually raised to the boiling point. The temperature is then allowed to decline to about 70° or 80° Fahr., when the object is taken out, wrapped in a cloth, and allowed to remain until dry. After this process the alabaster gradually assumes an opaque appearance. In former times alabaster was used in statuary, and some curious discoloured monuments in this material exist in some of our churches. The beautiful vases, pillars, and other ornamental works, which are turned in alabaster, require only a few tools in the working; namely, points for "roughing out," flat chisels for smoothing, and one or two common chisels, ground concave, and convex, for curved lines. The carved parts are done by hand with small gouges, chisels, &c., and are then smoothed with bent rasps and files, called rifflers, scraped with a triangular scraper, and further smoothed with fish-skin or glass-paper, and with Dutch rush used with water. In general, the smooth dead effect in carved alabaster is preferred, but where the polish of certain portions is required by way of contrast, those parts are worked with the end of a stick of deal, or other soft wood, supplied with Trent sand and water, and afterwards with a stick and putty-powder in water. The polishing of turned works is effected by taking a piece of fine soft sandstone, and applying it with water to the work, moving the sandstone all over it while it is in rapid revolution, until there is worked up a body of mud, then this mud is well rubbed with a wet rag on the alabaster, which is afterwards washed clean, and finished off with another rag charged with a mixture of putty-powder and soap and water.

Alabaster is not so often used by the lapidary as by the sculptor, but its treatment, when employed by the former, varies somewhat from the general practice with harder stones; therefore we give a short abstract of the description furnished to M. Holtzapffel by the best lapidaries:—

In working alabaster to the required forms, the lapidary first employs the slitting-mill, which is a thin plate of iron fixed on a vertical spindle, and made to revolve with moderate velocity, the edge being charged with diamond powder, and lubricated with the oil of brick. The alabaster is then roughly ground at a *roughing* or lead-mill, which is a flat circular plate of lead, fixed on a spindle, and travelling on a horizontal plane: this is abundantly supplied with coarse emery and water by means of a brush. The alabaster is moved to and from the centre of the rapidly-revolving lap, until all the marks of the slitting-mill are removed, and the stone is reduced to a flat surface. The alabaster is then smoothed at the same mill with flour emery, after which it is removed to the *wood-mill* to be smoothed. This is a disk of mahogany used with flour-emery and water: it is more effective than the roughing-mill, because more elastic, and because the slight roughnesses of its face from the rubbing up of the fibres of the wood act more quickly and satisfactorily than metal. The alabaster is now ready for polishing, which is accomplished at a *list-mill* with pumice-stone and water; but as the list, which is wound on spirally, is very elastic, flat works must be lightly applied, or they will sink into the soft face of the list-mill, and become rounded at the edges. The polishing is completed at a leather lap, or thick piece of buff-leather, pasted on a wooden disk, and supplied with fine putty-powder and water. Sometimes the naked hand, and a little moistened putty-powder, are finally used for the last polish. Amber, coral, jet, malachite, steatite, turquoise, and some other substances, are treated in nearly, or exactly the same manner as alabaster.

The cleaning of alabaster is effected as follows. The soiled object is immersed in cold spring-water for four or five days: the water is then changed, and a small quantity of lime is added, in which solution the alabaster is allowed to remain four or five days longer. It is then thoroughly rinsed, and exposed to dry in the open air. If the process fails on the first trial, it is repeated, and sometimes a third application becomes necessary. Earthenware-pans should be used, as wooden tubs stain the alabaster. Objects that consist of several pieces will be severed by this process, but can easily be re-united with plaster-of-Paris. The pores of the alabaster will also be opened, and it will exhibit its natural granular and sparkling appearance; but the more opaque effect can be restored by using putty-powder, applied with a rag or stick.

Oriental alabaster is a compact substance differing materially from the above; it is a stalagmitic carbonate of lime, of the same hardness as marble, and used for similar purposes. It is found of all shades, from white to brown, and sometimes veined with coloured zones. The magnificent Belzoni sarcophagus, purchased by Sir John Soane for 1,000 guineas, and exhibited at his museum, is of stalagmite. There are also fine specimens in the Egyptian Gallery of the British Museum.

HÆMATITE, or red iron ore, from the Greek, in allusion to its blood-red colour; but the original meaning of the term is so far lost, that mineralogists speak of *brown* and *black* hæmatite. [See IRON.] Fig. 1117 is a representation of a specimen of red hæmatite.

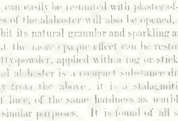

Fig. 1117.

HAIR, as an object of manufactures, is of various sorts, such as *human hair* and *horse hair*. The former is used chiefly for making wigs; the latter, including ox-tail, cow-tail, and even pig's hair, or brushmaker's waste, forms what is called the horse-hair manufacture.

Human hair is chiefly imported from France (which produces the finest and softest hair), from the north of Germany, and from Italy. Smaller quantities are obtained from Great Britain, India, and China, and also from Bohemia, Austria, and Belgium. Hair from India and China is too coarse to be of much value; that from Germany is light and flaxen; that from Italy, long and dark.

The annual value of the imports is roughly estimated at only £15,000, but the trade still gives employment to many thousands of persons in the manufacture of wigs, fronts, &c., notwithstanding the change of fashion, which has led to a comparative disuse of false hair.

The price of human hair varies from 4*s.* to 30*s.* per lb., although as much as 80*s.* per lb. is frequently paid for choice parcels of goods.

The average weight of a French head of hair (reckoning only the long back hair, the front hair being seldom cut), is 5 ozs., Italian, 6 ozs., German, 10 ozs. A manufacturer can easily distinguish the hair of each nation by its texture and odour. The time and labour bestowed on the article to bring it into a state fit for use by the wig-maker, is such as to raise its value 300 to 500 per cent.

False hair has been greatly in favour at various periods of our history; while among the ancients we have traces of the same custom, witness the splendid peruke found in the Temple of Isis, at Thebes, and now in our British Museum.

Wigs are said to date in England from the time of Stephen. In the wardrobe of Elizabeth was an item —"One cawle of hair set with pearls." James I. set the fashion of a *love-lock*, or curl considerably longer than the rest. The Puritans marked their sense of "the loathsomeness of long hair" by wearing their hair so short as scarcely to cover the ears; but in the reign of Charles II. periwigs attained an enormous size. Pepys records the payment of £3 for a wig, for which he sacrificed his own hair, and an agreement with his barber to keep his periwig in good order at 20*s.* a year. In the reigns of James II. and of William and Mary enormous full-bottomed wigs were worn by the learned professions. George I. adopted a plaited tail, with a large bow at the top and a small one at the bottom. This degenerated into the pig-tail under George II., which curious appendage still lingered at the beginning of the present century. False hair is more skilfully used at present, and is scarcely recognised from the real.

The best horse-hair is collected in the various towns of England, from ostlers and others, and sent up to London in sacks; long tail hair will fetch as much as 2*s.* per lb.; short and inferior hair not more than 8*d.* Foreign hair, and that of wild cattle, is inferior to English, on account of the lower feeding abroad.

When the hair is received at the factory it is sorted into colours, such as *best* and *seconds black* or *grey;* into qualities, as *soft* or *hard,* and into lengths suitable to the three purposes of *curling, spinning,* and *weaving.*

Curled hair, such as is used for stuffing sofas, chairs, carriage seats, &c., is prepared from the sorted short black or short grey. It is first *carded* between two large coarse cards, one of which is fixed at an angle of about 45° to a bench, and the other is worked by the hand, the operator sitting all the time. By this system of rough combing the hair is freed from scurf and dirt, and disentangled. The next process, called *tipping*, is performed by a boy, who, kneeling on the floor, with a cane in each hand, tosses about a quantity of carded hair, so as to let it fall in a tolerably regular tuft or *top*, which he consolidates by inflicting upon it a rapid succession of blows. One of these tops is then taken by a man, who attaches it to a wheel, which he causes to rotate rapidly by swinging round the top, and he thus spins or *curls* it into a hard rope; but before he has quite finished one top he works another into the loose ends, and then spins the second, and in this way he proceeds until he has spun a dense line of considerable length. He stops the wheel every now and then to wind up the finished rope upon it, and when a certain length has been spun, it is taken off the wheel, tied up into a bundle, and with other similar bundles, *steeped* in a cistern of cold water for three or four hours; then taken out, and, while still wet, put into a very hot oven, the heat of which is gradually let down during about twenty-four hours. The ropes are next *opened* by slightly untwisting in the opposite direction, then *towsing* or picking to pieces, when the hair will be found to possess that remarkably springy character which so well fits it for stuffing cushions, &c. The short sorted white hair is also used for brushes.

Hair of medium length is spun into a coarse thread, which is employed in weaving a coarse horse-hair cloth, such as is used for nose-bags for horses, filtering bags, and for some other purposes. This hair is also spun into clothes-lines.

The long hair is sorted a second time, and straightened by being thrown upon heckle points and pulled out many times. It is further separated into lengths by fixing the *heads* or thick ends of the hairs between the teeth of a couple of cards, and pulling out the longest ends by the points or opposite ends. By repeating this process two or three times, the hairs are separated into lengths with great precision. These are tied up by the heads into tufts, and are employed in weaving damask hair-cloth, such as is used for covering sofas, chair-bottoms, &c. In this kind of cloth the warp is of black linen yarn, and the weft of hair, which is thrown in with a long hooked shuttle or rod, with a catch-hook at the end. The shuttle is passed into the shed of the warp, and a child, placed on one side of the room, presents a hair to the weaver near the selvage, who catching it with the hook of his shuttle, draws it out on the other side: the batten is then driven home twice, and another shed or shuttle-way opened by the treddles: thus each weft thread is formed by a separate hair. The hairs are kept in a bundle in a vessel of water, to make them sufficiently supple for weaving. When the web is complete it is hot-calendered to give it lustre.

In this way horse-hair cloth is produced from 14 to [illegible], and even 40 inches in width. The latter width is, however, very unusual, and a long time is required to pick out and collect a sufficient number of hairs for the purpose.

A hair-cloth is woven for sieves, boys' caps, and other purposes. The long white hairs are used for stringing pearls, for fiddle-bows, for fishing-lines, &c.

Horse-hair can be bleached nearly white, and it takes various dyes tolerably well.

Horse-hair wigs are made of what is called *dead* hair, or the hair of horses which are out of condition, so that the nutriment to the hair being stopped, it dies and assumes a chalky appearance. A mixture of black and white hairs produces a grey. The dealers in hair know their markets so well, that they will not only separate live from dead hair, foreign from native, but they can tell with tolerable accuracy what part of Great Britain any specimen submitted to them may come from.

HAMMER. The hammer is perhaps the most remarkable and valuable of all the implements which man employs in moulding and submitting to his use the various objects around him. It illustrates the principle of the *permanence* of the force of communicated motion: it constitutes the force of impact, and is the most powerful of weapons. "Were there no tendency to *permanence* in the force of motion which his hammer acquires in its descent, its power on the substance which the artificer seeks to shape out would only be the same as though he were to lay it gently down upon it: its impact would be no greater force than the *pressure* of its weight. So far is this, however, from being the case, that, as it is well known to the workman, a slight blow from the lightest hammer is sufficient to abrade a surface which the direct pressure of a ton weight would not make to yield. There is no force in nature comparable to that of impact."

The term hammer is usually applied to the well-known tool consisting of an iron head fixed crosswise upon a handle of wood; but the hammers employed in the useful arts are very varied in form, and the weights of individual examples may be estimated from that of several tons to a fraction of an ounce. The largest hammer is the *helve*, or *forge-hammer*, used in the operation of shingling in the manufacture of *iron:* this weighs from 4 to 8 tons.—See IRON and STEEL, Fig. 1238. The helve is also used in forging *steel* ingots; but when they are sufficiently reduced by this means, the *tilt-hammer* comes into operation, and is made to move with great rapidity under the action of springs instead of by gravity alone.—See IRON and STEEL, Fig. 1241.

In the ordinary practice of FORGING, the smith employs a variety of hammers with the *panes* or narrow edges made in different ways, either at right angles to the handle, parallel with the same, or oblique: but the work done by these hammers is often accomplished with more precision by what are called *set-hammers:* those with flat faces are made like hammers, and usually with similar handles, and for the convenience of reversing are not wedged in: these tools, instead of striking, are struck upon the work with the sledge-hammer. Other similar tools, with broad faces, are called *fullers:* top-tools, with narrow round edges like the pane of the hammer, are called *top-fullers:* they are held to the work with hazel-rods, as noticed in the article CUTLERY, where the hammers used by the Sheffield cutlers are described. The hammers used in forging blanks for files, and for cutting the teeth, are described under FILE. The *hand-hammer* used by the smith is of such weight that it may be governed with one hand at the anvil. The *sledge-hammer* and the *monkey*, or *vertical-hammer*, are noticed in FORGING. The sledge-hammer has its varieties, which usually consist of the *up-hand sledge*, which is used with both hands, and seldom lifted above the head, and the *about-sledge*, which is held by both hands at the furthest end of the handle, and being swung at arm's length over the head, is made to fall upon the work with as heavy a blow as possible. Referring to the sledge, Mr. Holtzapffel remarks: "It is used [illegible] for light work; the right hand being slid towards the head in the act of lifting the hammer from off the work, and slipped down again as the tool descends: and the conditions are scarcely altered when the smith swings the hammer about in a circle, the signal for which is 'About sledge;' whereas when, in either case, the blows of the sledge-hammer are to be discontinued, the fireman taps the anvil with his hand-hammer, which is, I believe, an universal language." The *riveting-hammer* is the smallest used by smiths.

In the practice of forging, small tilt-hammers to be worked by the foot have often been introduced; but they are not successful, because, when one man has to manage the whole, his attention is too much divided, nor is his strength equal to the work. The best form of these *lift-hammers* is that called *the Oliver*, Fig. 1118. "The hammer head is about 2½

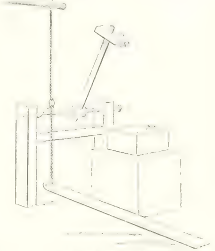

Fig. 1118. THE OLIVER.

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(1) [illegible]

inches square, and 10 inches long, with a swage tool, having a conical crease attached to it, and a corresponding swage is fixed in a square cast-iron anvil block, about 12 inches square, and 6 deep, with 1 or 2 round holes for punching, &c. The hammer-handle is from 2 to 2½ feet long, and mounted in a cross spindle nearly as long, supported in a wooden frame, between end screws, to adjust the groove in the hammer-face to that in the anvil-block. A short arm, 5 or 6 inches long, is attached to the right end of the hammer axis, and from this arm proceeds a cord to a spring-pole overhead, and also a chain to a treadle a little above the floor of the smithy. When left to itself, the hammer-handle is raised to nearly a vertical position by the spring, and it is brought down very readily with the foot, so as to give good hard blows at the commencement of moulding the objects, and then light blows for finishing them." Mr. Holtzapffel saw this machine at work making long, stout nails, intended for fixing the tires of wheels, secured within the felloes by washers and riveting: the nails were made very nicely round and taper, and were forged expeditiously.

The *raising-hammer*, for RAISED WORKS IN METAL, is rounded at the edge, and of various forms. The *planishing-hammer* has a flat, smooth face. In plated goods very expert hammering is required to remove the bruises produced in the raising, and to drive them to the copper side. This is done by hammering on the face with a smooth planishing-hammer, and covering the bottom tool with cloth. When, however, the inside of a vessel is to be smooth the hammer is covered with cloth, and the polished head within the vessel is left uncovered. Where both sides are to be bright the faces of both hammer and anvil are muffled. [See PLATING.]

The *goldbeater's-hammer* is a somewhat rounded one; the *hack-hammer*, for correcting distortions which so commonly occur in hardening steel goods, terminates at each end in an obtuse chisel edge. The hack-hammer used for hacking grindstones is a small adze of 2 or 3 lbs. weight, but longer and more curved in the blade, and with a very short handle. Its use is to hack or notch the high places which occur in large grindstones, in regular work, and arise from unequal wear. For this purpose the high places are marked by holding a piece of chalk or charcoal steadily upon the horse, and bringing it gradually near the stone before it comes to rest, the strap having been thrown off. The grinder then cuts shallow oblique furrows, about an inch apart, in the high places denoted by the marks, and crosses them with others so as to produce a chequered surface. On again using the stone the greatest wear occurs at these roughened places, and thus the stone is restored to its true form.

The *veneering-hammer* is of iron, with a very wide thin pane; but it is often formed of wood.

The STEAM-HAMMER will be described under that head.

HARBOUR is the general name given to any haven or port communicating with the sea, or with a navigable river or lake of sufficient depth to float ships of considerable size. A good harbour should be free from rocks or shallows: the opening should be of sufficient extent to admit large ships at all times of the tide: it should have good anchorage ground, and be easy of access, and well defended from the violence of the wind and of the sea: it should be sufficiently capacious for the reception of the shipping of different nations and deep enough to allow ships to lie close alongside quays or piers, that the expense and inconvenience of loading and unloading by means of lighters may be avoided: it should be furnished with a good lighthouse, and have proper rings, posts, moorings, &c., to remove or secure vessels. Portsmouth, Milford Haven, and the Cove of Cork, are the finest harbours in the British Islands, and are surpassed by few, if any, in the world. The accompanying steel engraving represents the harbour of Whitehaven in Cumberland, situate at the upper end of a small creek of the Irish Sea. This harbour is spacious and commodious, having seven piers extending into the sea in different directions, and affording ample security to shipping. Attached to the harbour is a patent slip; there are two lighthouses at the entrance, and a third situate on the promontory of the Bee's Head, 3 miles to the south-west. The commerce of this harbour is very extensive.

HARDWARE, a term applied to goods manufactured from metals, such as iron, steel, copper, brass, &c. Birmingham and Sheffield are the chief seats of the manufacture in this country.

HARPOON, or HARPING-IRON, a javelin used for piercing whales in the whale fishery: it has a broad, flat, triangular, barbed head, sharpened so as to penetrate easily, and a shank about 2 feet long, to the extremity of which is fastened a long line coiled up in the boat, so that it may run out easily without entangling.

HARTSHORN, See AMMONIA.

HAT. The manufacture of hats brings into operation the curious and interesting process of *felting*, which is the interlacing of animal fibres so as to produce, without weaving, a dense and compact cloth. This is caused by the peculiar structure of the hair and wool of animals, which though apparently smooth and regular, may be detected under the microscope as notched or jagged at the edges, the teeth invariably pointing upwards, that is, from the root towards the point. From a similar example in the vegetable world, namely, an awn of barley, we find that where this notched structure exists, the fibre when rubbed will move in one direction only. An awn of barley, root upwards, will travel up the coat sleeve, by the slight friction between it and the arm. The same kind of motion, though inferior in degree, is possessed by fibres of clean wool and hair, so that when subjected to gentle friction, assisted by moisture, the fibres mat together and form the kind of cloth called *felt*. The felting property of wool is greatly assisted by the crinkled or zig-zag figure of the fibre, which is retained with great pertinacity, so that if drawn out straight, it immediately contracts again on being let go; thus the forward motion of

the fibre, under friction, is partly counteracted, or converted into a circular or zig-zag motion, which is just that which most completely effects the matting together of the various fibres. So great is this tendency, that in a flock bed or mattress the carded wool of which it is made is constantly felting itself into knots, and requires to be pulled apart or to be carded afresh at intervals. Wool in the yolk, or with the natural grease adhering to it, cannot be felted, the roughness of the fibre being in that case filled or smoothed over by the oil.

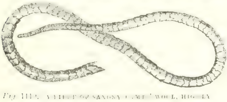
Fig. 1119. FIBRE OF SAXONY LAMB'S WOOL, HIGHLY MAGNIFIED.

A remote origin is ascribed to felt, which is said to have been the *lana coacta* of the ancients, worn as cloaks by soldiers, and to have been the material of the Lacedemonian hats. But the word rendered *felt* by some writers, is by others translated *knitted wool*, therefore, without occupying ourselves with the early portion of its history, it may be sufficient to state, that towards the close of the sixteenth century there is no doubt of its employment, for beaver hats were then in use in England, and became so popular, that in the next century Heywood, writing of varieties of head gear, concluded with, "But of all *felts* that may be felt, give me your English beaver."

An old hatter informed the writer, that in his youth an annual festival was held on St Clement's Day, (23d November,) this saint being the reputed inventor of felt, and that in Ireland and other Roman Catholic countries, the hatters still hold their festival on this day. St. Clement, perhaps, was the saint who is said to have put carded wool in his sandals to protect his feet on a pilgrimage, and who found at its close, that the wool had felted itself into cloth.

Beaver hats were at first regarded as a great curiosity, and fetched a high price, considering the value of money in those days. In 1585, Stubbs wrote, "And as the fashions be rare and strange, so is the stuffe whereof these hattes be made divers also; for some are of silke, some of velvet, some of taffatie, some of sarcenet, some of wooll, and, which is more curious, some of a certain kind of fine haire. These they call beaver hattes, of xx, xxx, or xl shillings price, fetched from beyonde the seas, from whence a greate sorte of other vanities doe come besides."

The supply of beaver for this manufacture is received through the Hudson's Bay Company, but owing to the gradual extermination of the beaver in many countries where it was once common, and the consequent failure in the imports of beaver, the fur of several other animals is come into use as a substitute. Thus the hair of the Coypou, whose skin is sold as *nutria skin*, that of the musquash or musk-rat, the fine down from the back of the common hare, and the fur of the rabbit, are all used in the hat manufacture. The furs in question form the nap of the hat; the body of the hat is made of lamb's wool, carefully washed, scoured, dried, and carded. The woolly hair of the Llama, or Vicuna, a species of camel, native of the Andes, is also used for the purpose. The structure of some of these hairs is shown in the following figures.

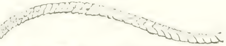
Fig. 1120. STRUCTURE OF BEAVER DOWN.

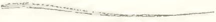
Fig. 1121. MUSQUASH.

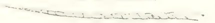
Fig. 1122. NUTRIA.

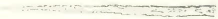
Fig. 1123. HARES' DOWN.

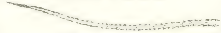
Fig. 1124. RABBITS' FUR.

The manufacture of hats from beaver, or from the furs used as substitutes, is conducted in the following manner; but it must be premised, that the demand for such hats is now comparatively small, on account of the perfection to which silk hats have been brought. The first operations belong to the furrier, and consist, first, of the cleansing of the skins by thorough washing in soap and water, after which the long coarse hairs are pulled out by a woman seated on a low stool, with the skin fastened to her knee by a strap passing over the skin and under the foot. She pulls out the long hairs by the roots with a jerking motion, seizing them between the thumb and the edge of a blunt knife. After all the long hairs are removed by this process, which is called *pulling* or *forcing*, the fine down or fur is next shorn from the skin by a sharp blade, applied either by hand or by machinery. By a simple but effective contrivance, the fur is then sorted into different degrees of fineness. A current of air conveys it along a horizontal trunk and as it floats along, the filaments are separated, and are carried to a greater or less distance according to their weight, the coarse and heavier filaments falling down first, and the finer and lighter continuing longer afloat, and being deposited considerably in advance. Thus, when the blast of air ceases, it is only necessary to open the trunk and select the various qualities as they lie ready sorted to the hand.

The succeeding operations are carried on in the beaver-hat factory. According to the kind of hat required, the beaver, some inferior fur, or lamb's wool, are selected for operating on. The beaver hat, properly so called, consists of a body or foundation of rabbit's fur and a beaver nap, but the latter is frequently mixed with some other fur. Another kind of hats made with the body of lamb's wool, and the nap of musquash, nutria, or some cheaper fur than beaver. This is called a *plate* hat, to signify, probably, that the outer layer only is of fur, the inner of felted wool, just as in plated articles the outside only is of the genuine material. A third kind of hat is the *felt* hat, in which the body is of wool and no nap is added. Supposing the hat to be one in which the body is of wool, and the plate or nap is of a superior kind, the processes are as follows. In the factory visited by the Editor, the fur is weighed out, mixed, and formed into a nap, in a low unventilated apartment, where every precaution is adopted to keep the air stagnant, that none of the precious material be wafted away and lost. One side of this apartment is occupied by a broad bench or counter, partitioned off into spaces of about five feet every way, each space being lighted by a window, constructed so as not to open. See Fig. 1125. Before each window stands a workman, performing the delicate and ingenious operation of *bowing* the fur, and making it into a nap. He first weighs out, say an [illegible] beaver, [illegible] quarter of an ounce of musquash, and the same quantity of cotton wool. These three substances are placed on the bench in a heap, which might be covered with the palm of the hand. He then takes in his left hand a bow about seven feet long, which is also kept steady by means of a cord suspended from the roof, and gives repeated and sudden vibrations to the string used for this purpose [illegible] with a peg [illegible]. At every vibration of the string against the heap of fur, a quantity of the filaments spring up several inches, [illegible] to the right of the bow, and fall down [illegible] in heaps in which they are [illegible] a wicker frame [illegible] shaped like [illegible], and set up with its concave surface towards the fur. By this process of bowing, all the fibres of the tangled mass are separated and rapidly distributed over a surface of several square feet in the course of a few minutes. The operation is repeated a second and third time, and such is the dexterity attained by the workman, that he seems able by the vibrations of his string to make the filaments fall into any required shape or position. When the fur is thus distributed into a large oval sheet, it is next pressed together so as to condense or *harden* it. The convex surface of the basket, and afterwards the hands, are employed to mat and interlace the fibres of the sheet of *napping*, as the fur is now called; and in order to complete the process, a skin of leather is interposed, and rubbed firmly with both hands, with a somewhat jerking motion, the skin being taken up and put down again in a different position several times. The use of this skin, called the *hardening skin*, tends to complete the interlacing of the fibres of the nap, and to produce a felt like thin flannel. The sheet of napping can now be handled with impunity. It is a long oval sheet, similar to No. 1 in Fig. 1126, and this is folded together, first sideways, as in No. 2, and then endways, as in No. 3, and is measured while thus twice doubled, against the hat-body, or foundation on which it is ultimately to be placed. Hat-bodies are supplied to many of the town manufactories from provincial works which deal only in this article. They are commonly of wool, formed into conical caps, about fourteen inches high, and fifteen inches wide at the base. They are formed by the felting processes which come so largely under notice in this manufacture. If the sheet of napping, doubled as above, is deeper than the conical cap, or hat body, a portion of it is torn away and bowed again. From this waste a smaller sheet of napping is formed, and cut into strips for the brim of the intended hats, and for a thicker supply of nap to those parts which are most exposed to wear. At this stage of the operations, the workman proceeds to the hat-maker's battery, where, around an open iron boiler, there is accommodation for seven or eight men to work at a bench of

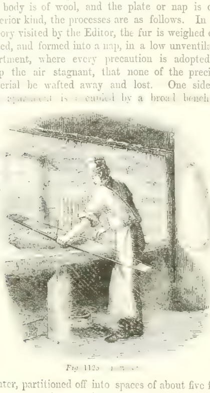
Fig. 1125. [illegible]

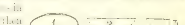

Fig. 1126.

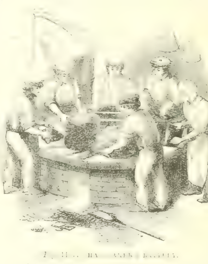
Fig. 1127.—HAT-MAKER'S BATTERY.

inclining, sloping towards the boiler. This is charged with soft water, containing about half a pint of sulphuric acid, and beer-grounds, or a handful of oatmeal, the former assisting in the removal of unctuous matters from the wool or fur, the latter correcting, it is said, the corrosive tendency of the acid. The whole is kept at the boiling point by a fire below, and the workmen pursue their task amidst clouds of steam. The conical hat-body is first held in the hot liquor, and when sufficiently soft is laid on the bench; a piece of beaver napping, sufficient to cover it, is gently laid on, the hat body is then turned over, and the napping, which is double, is unfolded and made to cover the other side also. The napping is sprinkled with hot liquor by means of a brush called a *stopping* brush, and is further worked with the hands, while hot liquor is occasionally poured into the body. Fresh nap is added from time to time, and that which is to form the under surface of the brim is put on when the hat body is turned inside out. A hair-cloth is next laid upon the bench, and upon this the napped body is rolled with a rolling pin, and worked in various ways by the hand, or rather by smooth pieces of wood covering the palm of the hand, and tied at the back with strings. These are called *gloves*.

The object of all these manipulations is the felting together of the nap and the foundation. When this is accomplished, and the roots of the fur have actually struck into the hat-body, the workman is immediately made aware of the fact, by the loosening and coming away of the cotton wool, of which it has been seen that a very small quantity was mixed with the fur at the commencement of the process. This cotton wool is incapable of felting, and, therefore, affords a valuable indication to the workman, by falling off when the other materials are felted, while in the previous stage it was of use in giving substance to the nap, and in effecting a saving in the quantity of beaver employed. Were the workman to continue rolling and pressing too long, the hairs of fur would pass completely through the hat-body and be found on the inside; therefore, it is important to know when to stop. Up to this point the napped hat-body still remains a loose conical cap, without any resemblance to a hat. But by pulling it and adjusting it with the hands, it is now capable of being drawn over a cylindrical block, on which it is tied with a cord. After much rubbing and pressing, the conical top is flattened into a crown, and the whole is adjusted to the shape of the block, while the brim, which is at first a puckered appendage, is also gradually worked into shape. The hat is now gradually dried in a hot room, and is afterwards made ready for dyeing, by first raising the nap by means of a carding-comb, and then cutting off the tips of the hairs so as to make them all of one length. This shearing requires a skilful hand, or the nap will be unequal or in furrows. It is done at one cut of the shears down the side of the hat, thus passing round and round the hat many times. The hats are further prepared for dyeing by being softened at a hot bath, called a *blocking-kettle*, and again drawn over wooden blocks.

When a number of hats (generally 5 dozen, called a *suit*,) have been thus prepared, they are hung on pegs within an iron cradle, and thus lowered, by means of a crane, into the dye-copper, Fig. 1128. Here they are immersed in a preparation of sulphate of iron, and galls and logwood, in water, forming a strong black dye. The cradle is allowed to remain in this dye, at a temperature of 180°, for about twenty minutes, when it is raised and left to drain for half an hour: this dipping and draining are repeated 13 or 14 times, until a bright glossy black has been obtained. The hats are now removed from the cradle to the blocking-kettle, the blocks are taken out, and the hats washed in separate vessels of water, to remove any loose dye stuff; they are then put on a rack to drain, and lastly removed to the drying-room, which is heated to 160° or 170°, and where they remain on racks till the drying is complete. They are then subjected to a few finishing processes, the first of which is the picking out of coarse hairs by means of tweezers. Notwithstanding the care which is taken in sorting the down, there are always scattered hairs, which become conspicuous at this stage of the manufacture for their harsh and coarse appearance, and require to be removed. This being completed, the crown is next strengthened by inserting a piece of scaleboard, called a *tip*, on its under side, and pasting a piece of linen over it to keep it in place. A block is then put in, and the general surface of the hat is dressed and improved by means of warm and damp hair-brushes, hot irons, and a plush cushion called a *velours*, or *velure*. If there are any refractory hairs which cannot be made to lie smooth by these means, they are burnt off by waving the hat rapidly through a large flame produced by shavings. The hat is then delivered over to women to be trimmed and bound, and to have the lining and leather sewed in; and, lastly, a superior workman finishes off the whole by blocking and setting up the hat in the most fashionable style.

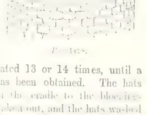

Fig. 1128.

One of the recent improvements in beaver hats consists of a hat-body of silk and a thin beaver *pull-over*, as it is technically called. The method of making the latter deserves notice on account of the felting process by which it is accomplished, and which may be taken likewise as a specimen of the mode of production of the woollen hat-body used in the ordinary beaver hat. The materials for the pull-over being weighed out and bowed, and the sheet of napping formed as before, the latter is at once made into a conical cap, instead of being simply folded together. For this purpose a triangular piece of brown paper is damped, and placed upon the sheet of napping, which is folded over it, and completely covers and encloses it except at the base. Fig. 1129 shows the pull-over enclosing the paper; the dark shaded portion representing the woollen hat-body lying upon it. Any superfluous portions of the napping are removed, and are bowed again and used to form the brim and thicken the parts requiring most strength. The brown paper remains within, while the cap is folded up in a damp cloth, worked about with the hand, pressed, bent, rolled and unrolled many times, whereby the fibres unite more closely. For a woollen hat-body a metal plate or bason is put within the cap instead of brown paper, the object being in each case to keep the sides of the cap asunder, otherwise they would felt together, and make a flat cone. On account of this the process is called *basoning*, even when paper merely is employed. The cap, thus formed, is twice as large as it will be when finished, for during the felting it shrinks greatly, and becomes thicker and more dense. The brown paper being removed, it is taken to the mahogany bench, sprinkled with hot liquor, and worked about in a variety of ways. It is then a perfect felted cap, and can be drawn over the silken hat-body, of which it forms the nap. The blocking is then performed as before described, the hat is dried and stiffened, and the after-processes are proceeded with as in the former instance.

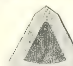

Fig. 1129.

The manufacture of silk hats is less interesting than that of beaver, inasmuch as the felting process is altogether absent. The operations are, in fact, entirely different: no conical caps are made; no hat-maker's battery, or blocking kettle, or dye-copper, is required. The hat-body is constructed on a block which consists of five pieces, forming, when put together, as in Fig. 1130, the oval shape of a hat. This block, being set up on a bench, a piece of calico is folded round the side of the hat, and the meeting edges are made fast by a solution of shell-lac. The whole of this layer of calico is then covered with cement, and another layer is then added and treated precisely in the same manner. The projecting edges at the top are then turned down upon what is to form the crown, and over it are cemented, in succession, three layers of calico, the last layer being also cemented on the outside. When these are all dry, a hat-body without a brim is produced. To make the latter, an oval piece of calico is cemented to a piece of twilled material, the latter being stronger and more absorbent of cement. The centre of this oval is cut away to suit the size of the hat, leaving a brim, which is secured to the hat by cementing one loose edge to the inside, and the other to the outside. A piece of calico saturated with cement is also bound, and ironed round the hat, to keep the brim firmly in its place: this is called a *band-robbin*. When quite dry, the proper width is given to the brim by means of a *rounding-brass*, or gauge, with notches, Fig. 1131, into one of which a knife is fitted, and in passing round the brim cuts off the superfluous portion. The hat-body is thus completed, and the method of covering it is equally simple.

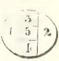

Fig 1130.

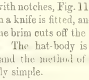

Fig. 1131.

The material for covering silk hats is a silk plush, woven like velvet in a loom with three treadles, and having a velvet nap or shag on one side. This fabric is manufactured in Spitalfields, and at Coventry and Banbury, but the chief supply is imported from Lyons. The plush is received in pieces of 20 or 30 yards long, and 26 inches wide, and great nicety is required in cutting it out, that none of the material may be wasted. It is cut into three distinct forms, namely, a circular piece for the crown of the hat, a rhomboidal piece for the side, and a long strip for the brim, rather wider than is sufficient to cover both its sides, and sewn together at the ends. The crown and side piece are sown together, so as to form a bag or cover to the hat, having a diagonal opening at the side. To put this on smoothly and well is a work of some dexterity. The calico hat-body, which is covered in every part with a layer of dry shell-lac varnish, is now rubbed with sand-paper to remove roughnesses. The strip for the brim is then fitted on, covering both surfaces, and being made to adhere by the application of a wet sponge, and then a hot iron, which act on the cement below, and make it hold fast the plush which is pressed down upon it. It is necessary to have both hands at liberty in the nice adjustment of the plush to its foundation, therefore a brass wire, attached to a rope stirrup, is made to embrace the hat just at the angle formed by the brim and the body; and this wire enables the workman to gather up all puckers in the upper cover of the brim, and cut away the superfluous portion above the wire. Fixing the remainder by means of the sponge and iron, he next adjusts the under surface of the brim, where the wire is evidently not available, but a brass plate, Fig. 1132, of a semi-circular shape, let into the work-bench, answers a similar purpose in keeping the hat steady, and leaving the workman the free use of his hands. The superfluous portion of the plush is in this case not cut off, but turned up within the hat and secured to it. The plush-bag, or cover, has now to be drawn over the crown and sides of the hat, and adjusted so as to form a perfectly smooth surface. The diagonal line formed by the union of the parts is entirely concealed by the nap, but becomes visible in an old silk hat. Any fulness or tendency to pucker is drawn down into the band. Moisture and heat are applied as before to make the union of the parts perfect, and the surface smooth. A wire carding-comb is also drawn over the plush, which is further smoothed and made glossy by the application of a dummy

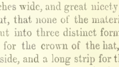

Fig. 1132.

of box-wood shaped like an iron, and of a velvet cushion.

The trimming and lining of these hats is performed by women, after which they are returned to the workshop to be tipped off, or shaped. A curl is given to the brim by the thumb and finger, after the part has been sufficiently softened by the sponge and iron. By holding the hat before a stove, the whole surface becomes soft enough to be moulded into any required shape: a hat-screw, then introduced, elongates the hat, while the shaping of the sides and brim can be easily performed by the hands. Imperfections in the nap are then removed by a steel picker, and the hat is polished and wrapped in paper for sale. So extensive is this manufacture at the present time, that for every beaver hat, it is calculated that 1,000 silk hats are fabricated.

We have not the means of furnishing the statistics of this important branch of industry at the present time. Some years ago England produced about 250,000 dozen of silk hats annually, of which more than half were fabricated in London. The annual value of the hat-manufacture, including beaver, silk, and wool-felts, is estimated at 3,000,000*l.* sterling. Many thousand dozens are exported, chiefly to the colonies. The beaver hat trade employs more subsidiary trades than the silk, on account of the preparation of fur, the making of long bows for the bowing process, &c.: the workmen also require a longer apprenticeship to learn the former than the latter trade.

Our notice of the hat-manufacture would not be complete without the mention of straw hats, which did not begin to form an article of British trade until late in the last century, although they were brought to great perfection in Italy more than two centuries ago. The importation of foreign goods having been interfered with by war, our own manufacture of this article rose into importance, and improvements in bleaching, plaiting, and finishing, as well as in the cultivation of indigenous grasses, were much encouraged by premiums from the Society of Arts. The straw of Tuscany, however, maintained its repute, and was plaited by our workpeople after the Italian method. This consists in first carefully sorting the straws as to colour and thickness, then counting a certain number, frequently thirteen, and tying them together at one end. They are then divided into two portions, six straws being turned towards the left side, and seven to the right, so that the two portions of straw are at right angles to each other. The seventh, or outermost straw, on the right hand, is then turned down by the finger and thumb, and brought under two straws, over two, and under two. There are now seven straws on the left, and six on the right, therefore the outermost of the left hand straws is now to be turned down, and passed under two, over two, and under two again. The plaiting is continued in this way, alternately doubling and plaiting the outermost seventh straw from side to side, until it is used up. Another straw is then put in under the short end, in the middle of the plait, and by the crossing of the other straws over and under it, the fastening of it becomes secure. This kind of plait, shown in Fig. 1133, of about double the real size, is formed in pieces of great length, which are adjusted according to the Italian method, in spiral coils, to form large flats, as they are called, the edges being adroitly knitted together in the manner shown in Fig. 1134, which gives the plait, for the sake of distinctness, nearly four times larger than the real plait.

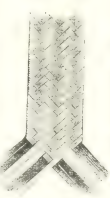
Fig. 1133.

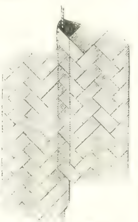
Fig. 1134.

The dotted lines show how far the angular folds or eyes of one piece are inserted into those of the adjoining piece. The thread which is run straight along in the interior is entirely concealed, and the join can only be detected by the slightly increased thickness of the plait. The best plaiters use the second finger with their thumb at their work, thus leaving the first finger free to turn the straws.

All the processes connected with the straw-hat manufacture, especially in warm climates, can be best performed in the spring, at which season there is also the largest demand for hats and bonnets of this material. The plaiting is much more perfectly executed in that temperate season than when the heat of summer has soiled, or the cold of winter has benumbed the fingers of the workpeople. No bleaching can effectually remove the tarnish communicated by warm and soiled hands, nor the tinge given in smoky rooms in cold weather. The large flats, above alluded to, are received in cases of from 1 to 20 dozen, varying in degrees of fineness. Names are given to the flats according to the districts which produced them. Florence is the principal market for the Italian hats.

British straw plaiting chiefly prevails in the counties of Bedford, Hertford, and Buckingham, but is carried on also in Essex, Suffolk, and other counties. When the straw is of British growth the process is as follows. The whitest and most regular straws are selected, and cut into equal lengths, then bleached by exposure to fumes of burning sulphur, and split lengthwise into several segments. To effect this a wire having four, six, or eight sharp edges is passed up the middle of the straw. The slips thus obtained are softened in water, and can then be plaited with great rapidity. The plait is passed between wooden rollers to make it flat and hard. The hat is formed from it by winding the plait on a wooden block of the required shape in a spiral direction, leaving a little overlap, which is sewed to the part beneath. The seams are afterwards pressed down with a hot iron.

This domestic and healthful employment affords subsistence to a great number of persons, and usefully employs women and children whose labours could not otherwise be turned to so good an account. At the present time there are probably from forty to fifty thousand persons engaged in the manufacture. There are many varieties of plait in general use, known as whole Dunstable, split straw, patent Dunstable, or double seven, Devonshire, Luton plait, Bedford Leghorn, Italian plait, &c. There are also endless fancy plaits. Hats of Brazilian grass, bonnets of plaited whalebone shavings, and other curiosities of manufacture, also appeal to the love of novelty of purchasers.

HEALDS.—See WEAVING.

HEARTH.—The flat or hollow space in a smelting furnace, upon which the ore and fluxes are submitted to the influence of flame. See COPPER—IRON, &c.

HEAT.—In its ordinary sense the term heat is used to denote a quality otherwise called high temperature, the reverse of cold or low temperature. In a scientific sense the term heat or *caloric* is used to denote that substance or action which by its greater or less abundance or intensity in matter produces effects which are also expressed by the terms high or low temperature.

In all inquiries into the effects of heat, it is necessary to attend to the following rules respecting the application of the term temperature:—I. If a body subject to no pressure, or to a constant pressure, have at two different times the same bulk, it is said on both occasions to have the same temperature.

II. Two bodies are said to have the same temperature if, being kept in contact, the temperature of either remains unaltered by the action of the other.

III. When bodies of different temperatures are in contact, the temperature of the hotter body decreases and that of the colder increases, till they become equal.

IV. If the bodies be equal in mass or in weight, and of the same substance, the increase of temperature in one will be equal to its decrease in the other.

Hence it will be seen that differences of temperature are measurable and comparable with each other, quite independently of change of bulk; that is, without using the latter as a *measure* of temperature, but only as a *test* by which change of temperature is detected. In this way it has been discovered that the *same* increment (not *equal* increments, as from 40° to 50°, and from 50° to 60°) of temperature causes all masses of the same substance to expand in the same ratio to their whole former bulk; but this is by no means the case with different substances, as is obvious by looking at a common thermometer, an instrument for measuring changes in the bulk of a mass of liquid contained in a glass vessel of such a form, that changes, very small compared with the whole bulk of the liquid, may cause its surface to rise and fall through a considerable space. Now, this could not be done if the glass and the measuring scale, in undergoing the same changes of temperature as the liquid, experienced also the same change of bulk; for, if such were the case, the liquid surface would always remain opposite the same degree on the scale. The value of this simple instrument, therefore, depends on the fact—that liquids are more expansible than solids.

But it will further be seen that the ratio of the *change* of bulk to the *whole* bulk is different for every different substance, when the change of temperature is the same in all. It is necessary, however, to guard against a very common error respecting the relation between *temperatures* and the *numbers* by which they are represented; namely, the degrees of the thermometer.

Although the *differences* of temperatures are known and comparable quantities, yet their *ratios* are not so. We can compare them by addition and subtraction, but not by multiplication or division. We cannot say, "*This* temperature is so many times *that*," because we do not know the real zero of temperature; that is, we do not know what is the smallest bulk into which a given body is capable of being condensed by cold. We cannot, therefore, say, "*This* body exceeds its minimum bulk by twice as much as *that* body exceeds its minimum bulk;" or, in other words, "*This* body is twice as hot as *that;*" for although the temperature of one body may be 80°, and that of another 40°, these numbers are only reckoned from an arbitrary zero or starting-point, adopted because the real zero is unknown. But although we cannot say that A has twice the temperature of B, we can say that the temperature of A exceeds that of B by twice as much as the temperature of C exceeds that of D.

The first question, then, regarding the relation of expansion to temperature, is—"Do equal differences of temperature cause the bulk of a body to vary by equal differences?" This question had to be settled before it could be known whether the common thermometer (the scale of which is divided into *equal* parts) measured differences of temperature correctly. For this purpose, Dr. Brooke Taylor heated two equal weights of water, one to 200° and the other to 100°, and on mingling them together, he found them to remain exactly 150°; thereby showing that equal differences of temperature cause equal differences in the expansion of mercury; or rather in the excess of its expansion over that of glass, which is clearly all that the thermometer can measure. More accurate experiments, however, have shown that this rule does not *exactly* apply to any solid or liquid, but only to *gases*. When equal masses of the same liquid, at different temperatures, are mixed, their combined bulk becomes a very little diminished. Liquids, therefore, instead of expanding by equal increments of space for equal increments of temperature, expand *faster* as the temperature increases *equably;* and it appears that the correctness of the mercurial thermom[illegible] by Dr. Brooke Taylor was the result of [illegible], by which the expansion of the glass, which is very small compared with that of the mercury, exactly compensated the increasing rate of the latter. This, however, would not be the case with thermometers constructed with other liquids, for their rates of expansion increase more rapidly than that of mercury. Hence spirit thermometers cannot be depended on for temperatures above the atmospheric range (or above 100°).

The rate of expansion in solids is also found to increase as they become hotter; but it is more equable than that of liquids. Instruments for measuring the expansion of solids are called *pyrometers* to distinguish them from thermometers, which measure the expansion of liquids and airs. The measurement of solid expansion is, however, by far the more delicate and difficult, not only from its smaller amount, but because we cannot measure at once the whole cubical increase or *expansion*, but only the increase of one linear dimension, that is, the *elongation* or *dilatation*. As solids do not in general alter their form by change of temperature, all the dimensions increase and decrease in the same ratio. The only known exceptions to this are afforded by *crystals*.

The first effect of heat on solids is expansion. If, however, the heat be more energetic, the solid is resolved into a liquid. The liquefaction of some solids is gradual; they pass through various degrees of softness; but in many, perhaps in most cases, there is no intermediate state between perfect solidity and perfect fluidity: the solid is heated up to a certain point, at which it remains solid; but a very slight increase of heat is then sufficient to liquefy a portion of it. Now, it is an important fact that the same substance always passes from the solid into the liquid state at precisely the same temperature, and this is called its *melting point* if it be above, or *freezing point* if below the ordinary atmospheric temperature. Thus the melting point of ice, or the freezing point of water, is 32° on the scale of Fahrenheit used in this country; but it is made the zero or 0° of the continental scales. The freezing point of mercury is about 70° Fahr. lower than 32°, and is therefore called − 38° (minus 38°), or 38° below zero, a degree of cold which in England can only be produced artificially. By these means almost every other body that is liquid at common temperatures has been rendered solid. On the other hand, there are very few solids which have not been melted by artificial heat, or by that of the sun concentrated; and each one has its fixed and unalterable melting point. Thus, tin melts at 442°, lead at 594°, zinc at 773°, antimony at 812°, and so on.

But there are important circumstances to be noticed in the liquefaction of these bodies. It is evident that if a quantity of ice, at the temperature of zero, or 0°, be taken into a room whose temperature is 60°, the ice will begin to melt; and a thermometer placed in it, which at first indicated zero, will rise and soon reach 32°; but at this point it will remain stationary [illegible] liquid form. Even if the vessel containing the ice be placed upon a fire, the mercury in the thermometer will not rise above 32° so long as any ice remains in the vessel. Now, it is obvious that, during this time, a quantity of heat must be constantly entering the vessel and rendering its contents fluid; and, since this quantity of heat is engaged in liquefying the ice, it produces no effect upon its temperature. Thus we [illegible] of the modes in which heat or caloric acts, and that when a portion of heat is producing the effect of *fluidity*, it cannot be at the same time producing the effect of *temperature*. The effect here described for ice applies equally to other solids. Hence we see that, during the process of liquefaction, a large quantity of heat disappears, or is *absorbed*, so as to be no longer sensible to the touch or to the thermometer. The heat thus lost is sometimes called the *heat of fluidity*, or *latent heat*, in contradistinction to the heat of temperature.

Another general effect of heat is the conversion of liquids, by an enormous expansion, into airs, gases, or vapours, as when water by boiling becomes steam. This effect is attended by the same important circumstance as in liquefaction, namely, the absorption or apparent loss of a large quantity of heat, which, however, reappears when the vapour is condensed again into the liquid form. A vessel of boiling water exposed to the atmospheric pressure of 30 inches maintains the constant temperature of 212°, and the most violent heat is insufficient to raise it above this point. The heat thus expended in vaporizing water without raising its temperature is sufficient to raise it no less than 970° if it were not vaporized; or, in other words, the latent heat of steam is nearly 1,000°.

Different bodies manifest different capacities for heat; that is, if two equal masses or weights, of the same temperature, receive the same amount of heat, they will not become equally hot, even although they do not change their state. For example, if a pound of mercury at 160° be mingled with a pound of water at 40°, the resulting temperature will not be the arithmetical mean, or $\frac{160 + 40}{2} = 100°$; it will be only 45°; so that the 115° lost by the mercury heats the water only 5°. On reversing the experiment, and mingling a pound of water at 160° with a pound of mercury at 40°, the result will indicate 155°; so that the 5° lost by the water raises the mercury 115°.

Different bodies, therefore, have various degrees of susceptibility to heat. To produce a certain change of temperature requires a greater supply of heat in some bodies than in others. Numbers proportional to the quantities of heat necessary to produce the same change of temperature in equal *weights* of different bodies are called the *specific heats* of these bodies, or their capacities for heat. Thus, water is said to have thirty times more *capacity for heat* than mercury.

There are three methods by which heat is diffused, namely, by *conduction*, by *convection*, and by *radiation*.

Bodies that are kept in contact will (if of different temperatures) gradually change till they acquire the same temperature; that is, their shares of heat of temperature will become proportional to their capacities, and each body will have the same temperature throughout its mass. But this diffusion does not take place instantaneously, or there would be no such thing as difference of temperature. The rapidity with which heat travels varies in different substances. For example, if we place a silver spoon and a wooden one in boiling water, the handle of the former will become too hot to be held before that of the wooden one is sensibly warm. We see, then, that silver is a good conductor, and wood a bad conductor of heat. Different substances conduct heat at different rates. If we call the conducting power of gold 1,000, silver will be 973, copper 898, platinum 381, iron 374, tin 303, lead 179, marble 23, porcelain 12, clay 11. On placing one hand upon a piece of fur or flannel, and the other upon a piece of metal, both of the same temperature, (as they must be if left under the same circumstances,) and both colder than the hand, we call one warm and the other cold. This is an effect of sensation merely. The metal, being a good conductor, abstracts heat from the hand and gives the sensation of cold; the flannel or fur, being a bad conductor, not only takes away no heat, but allows it to accumulate, and hence the sensation of warmth. Precisely the contrary effect will take place if both bodies are warmer than the hand. The metal will feel hottest, and will even burn us, at a temperature at which the cloth would hardly seem warmer than in the former case.

But in liquids there can be no change of temperature without a displacement of particles. If heat be applied to a vessel of water, the particles near the bottom of the vessel being heated first and expanding, become specifically lighter, and ascend; colder particles occupy their place and ascend in their turn, and thus a current is established, the heated particles rising up through the centre, and colder particles descending at the sides, as shown by the direction of the arrows in Fig. 782, (article EBULLITION.) This is evidently a very different process from conduction. The heat is not conducted from particle to particle without displacement, as in the case of a solid; but each particle, as fast as it receives a fresh accession of heat, starts off with it, and carries it to a distance, displacing other and colder particles in its progress. This process has received the appropriate name of convection, and its importance will be seen if we apply heat to the *surface* of a liquid instead of to its base. Water being a bad conductor, we may boil it at the surface, while a lump of ice sunk to the bottom will remain unmelted.

Gaseous bodies, however, from the great mobility of their particles, are the most rapid conveyers, although (and, indeed, *because*) they are the slowest conductors of heat. Any body hotter than the air sets in motion an upward current of that fluid, which may be easily seen rising from bodies that are much heated, and the particles which rise are immediately replaced by the influx of other particles from every side. The slightest difference of temperature is sufficient to produce these effects, and hence the rapidity with which the air reduces all bodies to its own temperature. A body colder than the air, such as a lump of melting ice, produces an opposite action: it cools the air in contact with it, which, becoming denser, descends in a continual stream, supplied by an influx of air from all sides to the ice, until the whole is melted.

Actions of the same kind in the great scale of nature give rise to all the varieties of *wind*, by which the whole mass of the atmosphere is kept in motion, and its temperature so far equalized as to mitigate the extremes of climate, and render both the equator and the polar regions habitable. Such effects as these could not take place if the great ocean of air were heated (as at first sight it may appear to be) from above. The atmosphere receives scarcely any of its warmth directly from the sun's rays, but is heated almost entirely by the ground on which it rests, and is, therefore, in the condition of the water in a boiler, where the heat is applied from below.

But it is different with the liquid masses of our globe. The heat is applied to them at their surface, and is therefore not diffused by convection. It creeps slowly downwards by conduction, so that the temperature of all deep waters is found to diminish downwards. In the absence of the sun, however, the process of *cooling* goes on by convection; the surface waters being cooled first, become denser, and therefore sink, while new portions are brought to the surface, where they are cooled and sink in their turn; by which circulation the whole would very soon be reduced to the freezing point, were it not that the wisdom of the Creator has ordained that the general law of rarefaction by heat and condensation by cold shall, between certain limiting temperatures, be reversed. Thus water contracts by abstraction of heat down to about 39½°, when it has attained its point of greatest condensation by cold; from this point to 32°, its freezing point, it expands by the application of cold. Hence the operation of this exceptional law gives rise (in water below 39½°) to a species of convection exactly the reverse of that in other fluids, namely, a convection of heat more readily downwards than upwards. Thus, above the temperature of 39½° masses of water are more easily cooled than heated; and below 39½° they are more easily warmed than cooled.

The third method by which heat is diffused is by *radiation*, as when we stand at a distance from the fire, and experience its warmth. The heat is not, in this case, brought to us by any current of air, for that must set in *towards*, and not *from*, the fire; and besides, heated currents tend constantly to ascend. Nor can it depend on the conducting power of the air, for that is very slow indeed, and we experience the heat of the fire instantaneously. From these and various other reasons, it is evident, that a substantial medium, path or passage is not necessary for the propagation of heat.

If a red-hot cannon-ball be suspended in the air, *rays* of heat will be emitted from it as a centre, in radial lines, which move with the velocity of light, and, like the luminous rays, may be reflected, absorbed, refracted, transmitted, &c., by encountering certain surfaces; and these rays may be reflected or transmitted without disturbing the temperature of the reflecting or transmitting surfaces; but if the calorific rays be *absorbed* (that is, if they are stopped, and wholly or partly cease to exist as *rays*), an immediate increase in the temperature of the absorbing body is the result. This transmission must not be confounded with conduction of heat. The latter is always a slow process, while the transmission of radiant heat, or calorific rays, is instantaneous. It is the peculiar property of these rays, that they do not heat bodies through which they pass, as conducted heat must do. The worst conductors of heat (air and gases) are the best transmitters of these rays, while the best conductors (metals) totally stop the progress of the rays.

The intensity of radiant heat diminishes in the ratio that the squares of the distances from the radiating points increase; that is to say, the heating effect of any hot body (such as the red hot ball above noticed) is nine times less at *three* feet than at one; sixteen times less at four feet; and twenty-five times less at five feet. Now, as this law applies to all influences that spread from a centre, such as gravitation, light, heat, electrical forces, magnetism, sound, and in fact all *central forces* when not weakened by any resistance, or opposing force, it is desirable to impress the law fully on the reader's attention by giving a reason for it. Suppose a board two feet square, Fig. 1135, to be held with its centre exactly two yards from a candle, and another board one foot square to be held parallel with the first board, and exactly half-way between it and the candle, it is evident that this will exactly intercept the whole of the light that would have fallen on the first board, and no more. But its area is only one-fourth of the first board. Hence we see that the same quantity of light which at *one* yard from its source covers *one* square foot, will, at two yards from its source, be spread over *four* square feet, and consequently be four times less intense. So, also, a board *one* foot square will intercept exactly all the light from another board that is *three* feet square, if the latter be three times as far from the candle; so that any portion of the latter board would receive only *one-ninth* as much light as falls on an equal space of the nearest board. Now, all this must plainly apply not only to light, but to any force that proceeds from a centre in straight lines or rays, and consequently to radiant heat.

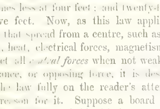
Fig. 1135.

All bodies, when raised to an equal temperature, do not radiate equal quantities of heat in equal times. It is, however, remarkable that the rate at which a body cools is influenced by the state of its surface more than by the nature of the material of which it is composed. A vessel covered with lamp-black and filled with hot-water will cool down to the temperature of the surrounding air almost twice as quickly as the same vessel with a bright polished surface. If we call the radiating power of lamp-black 100, that of writing paper will be 98, sealing wax 95, crown glass 90, plumbago 75, tarnished lead 45, mercury 20, clean lead 19, polished iron 15, gold, silver, copper, and tin, all polished, 12. It has been proved that the same surfaces which radiate most quickly also absorb rays of heat most quickly, and it is remarkable that these two properties are exactly proportional in all bodies, or, in other words, the same numbers which express the relative radiant powers of any list of substances (as above) will also express their relative absorbent powers.

By absorption we do not here mean the conversion of sensible into latent heat; but the conversion of radiant into conductible heat. Not all the radiant heat, or rather the radiant effect, which enters a body is immediately *absorbed* or converted into heat: a portion continues its course through the body without warming it; and though more and more is absorbed at every step, yet if the body be not thick enough to absorb all the rays, some of them will emerge on the other side and continue their course till, by the warming of the various media through which they have travelled, all their heating effect has been expended and they cease to exist as rays. The speed with which this is effected is enormously different in different media. Those in which it takes place most slowly are called the most *diathermanous*, but no medium, not even air, is perfectly diathermanous, though a thickness of many miles of it absorbs less radiant heat than a small fraction of an inch of most solids. Hence the atmosphere is scarcely warmed at all by the sun's rays passing through it, their effect being produced on the ground or sea, which in its turn warms the air, by convection, which is a necessary process in the production of *winds*.

Not all the radiant effect which falls on the surface of a new medium enters it; a portion is always reflected. *Radiations* or effects which are propagated in straight lines only (such as light and radiant heat), are most conveniently considered by dividing them into innumerable straight lines or *rays;* not that there is any such division in nature, but to enable us, amidst the extreme complexity of these phenomena, to confine our attention to the simplest independent portion of the effect. Every individual ray, whether of heat or light, proceeds in a straight line until it meets a reflecting surface, from which it rebounds in another straight line, the direction of which is determined by the law that the angle of incidence is equal to the angle of reflexion, to which, however, in this case must (on account of its generality) be added another condition, viz. that the *plane of reflection*, as it is called,

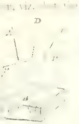

Fig. 1136.

(or that imaginary plane which contains both the incident and the reflected ray), is *perpendicular* to the reflecting surface at the point of contact. Thus, let a ray from A, Fig. 1136, fall on a reflecting surface at B. We must suppose a perpendicular to this surface erected at the point of incidence, as P B, which contains both the incident ray and the perpendicular, and also contains the reflected ray B C, both rays making equal angles with this perpendicular P B, but on opposite sides of it. When the surface is curved, a perpendicular or *normal* (as it is then called) can equally be erected at any point on it; for it must be remembered that each mathematical point of such surface acts precisely as a tangent plane, that is, as a plane touching the curved surface at that point would act. Thus it happens, that certain regularly curved reflecting surfaces, called concave or parabolic, possess some remarkable properties. For example, if a mirror have the form of a *paraboloid*, every portion of rays radiating from the point called its *focus* will be reflected into parallel directions, and any number of parallel rays coming to such a mirror are all reflected so as to meet in its focus.

In Fig. 1137, two such mirrors, A and B, are shown.

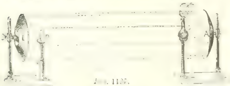

Fig. 1137.

They are made of metal, and highly polished, because we have seen that this kind of surface is the worst radiator, and therefore absorbs the least proportion of the rays that fall on it, and consequently must reflect the greatest quantity. If these mirrors be truly centered, that is, placed so that their axes may be exactly in the same straight line, and if a hot body be placed at C, in the focus of the mirror A, all the rays which it sends to that mirror will be reflected into parallel lines, and so reaching the other mirror B, will be reflected by it, and all brought to meet in its focus D, where a thermometer will be affected more than at any other spot, even though such other spot be much nearer the hot body C. Moreover, if a screen be placed either between C and A, or between B and D, the effect on the thermometer instantly ceases.

To render this experiment more striking, a red-hot iron ball is sometimes placed in the focus of one mirror, and some combustible, such as gunpowder, phosphorus, paper, &c., in the focus of the other. These bodies will be burnt, although their distances from the ball C may be 10 or 15 feet.

If, instead of a heated ball, we place in the focus of the mirror A a ball of ice, a thermometer in the focus of the mirror B will be observed to fall. When this experiment was first performed, it was supposed to arise from the *radiation of cold.* This, however, was a mistake; since no principle of cold, considered as a positive quality, can be admitted, cold being merely a sensation arising from the abstraction or diminution of heat; as darkness results from the absence of light, and silence from the absence of sonorous vibrations. In this experiment the thermometer sinks, because it radiates heat to the ball of ice. Hence we learn, that even a body at the ordinary temperature must be constantly radiating heat; and, of course, can only preserve its temperature by the counter-radiation it receives from other bodies. When two bodies are placed in the foci of the opposite mirrors, they are, as it were, isolated or cut off from any other source of heat, so that any heating effect observed in one must be derived from the other. The thermometer, therefore, in the last experiment, has a large proportion of its supply diminished much below its usual intensity, so that (its radiation remaining unaltered) its temperature must sink lower than usual.

These generalizations enable us to explain a still more remarkable instance of the apparent focalization of cold. If one of the parabolic mirrors be placed so that its axis[1] may point to the sun, as the rays coming from a body at so vast a distance are physically parallel, they will all be reflected to the focus of the mirror, so that it will act as a powerful burning mirror. But if the mirror be turned so as to face a portion of clear blue sky (the bluer and the nearer the zenith the better), its focus will become a focus of *cold,* and a delicate thermometer placed therein will sink, in clear weather, some degrees even in the day time, and as much as 17° at night.

Now, in order to understand this effect, it must be remembered that the thermometer is constantly radiating heat in all directions, and also receiving from surrounding bodies, in ordinary circumstances, just as much heat as it radiates. But in this experiment it receives less, because its usual supply from below is cut off by the mirror. But it may be asked, "Will nothing but a mirror serve this purpose?" Any other body would radiate from its own surface as much heat as it intercepts from other bodies; but a polished metallic surface, being the worst of radiators, supplies less heat than it intercepts. It must also have the form of a mirror, the focus of which must coincide with the place of the thermometer, because, if it had any other form, it would reflect to the thermometer some of the rays which it received from other bodies; but, because it is a paraboloid, it cannot reflect to its focus any rays except those that come in a certain direction, namely, parallel with its axis. Now, in that direction no rays come, for there is no body either to reflect or to radiate them. If a cloud, indeed, pass before the axis of the mirror, the thermometer rises to its usual height.

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[1] The axis of a paraboloidal mirror is [illegible] drawn from its centre through the [illegible]

The following are some of the miscellaneous effects of heat:—

	Deg. Fahr.	
Measured by [illegible]	−220	Greatest artificial cold yet produced. (By a mixture of [illegible].—*Natterer*.)
	−166	Cold produced by a mixture of solid carbonic acid and ether in vacuo.—*Faraday*.
	−121	Carbonic acid (liquefied by pressure) freezes.
	−58	Estimated temperature of the celestial spaces [illegible].
	−56	Lowest natural temperature observed [illegible].
	−39	MERCURY freezes.
Measured by Mercurial Thermometers.	−18	Greatest cold observed in England 25th Dec. 1860.—[illegible] feet above the ground.
	−7	Proof spirit (half alcohol and half water) freezes.
	4	[illegible] snow and salt.
	0	[illegible] the common atmospheric pressure.
	5	Saturated brine freezes.
	7	Spirits containing 25 per cent. of alcohol freezes.
	14	Oil of turpentine freezes.—Sulphurous acid boils (common pressure).
	20	Strong wine freezes.
	[illegible]	Sea-water freezes.—[illegible] Milk [illegible].
	32	WATER freezes, or ice melts.
	36	Olive oil freezes.
	[illegible]	Water is [illegible].
	50	Oil of aniseed freezes.—Mean temperature of England.
	52	Mean temperature of London.—[illegible].
	70	Nitrous ether boils under the common atmospheric pressure.
	[illegible]	Mean temperature of [illegible] in Africa.
	95	[illegible]
	97	Pure ether boils under the common atmospheric pressure.
	98	Human blood, heat of [illegible].
	111·5	Phosphorus melts ([illegible].)
	[illegible]	Greatest atmospheric heat observed by Burckhardt in Egypt.—Ditto, by Humboldt, in Cumana, &c.
	[illegible]	Wax melts (or becomes transparent).
	173·5	Pure alcohol boils under the common atmospheric pressure.
	201	The fusible alloy of tin, bismuth, and lead melts.
	212	WATER boils under the common atmospheric pressure.
	225	Saturated brine boils.—[illegible] Sulphur melts.
	[illegible]	Heat obtained from the solar rays, by Saussure. ([illegible], by Herschel.)
	[illegible]	Saturated [illegible] of potash boils under the common pressure.
	[illegible]	Oil of turpentine boils.—[illegible] Camphor melts, and boils at [illegible].
	[illegible]	[illegible] 451, Tin melts.
	[illegible]	Sulphur [illegible].
	497	Bismuth melts.
	554	Phosphorus boils.
	570	Sulphur boils (under common pressure).
	600	Linseed oil boils (under common pressure).
	617	Lead melts.
	[illegible]	Strongest oil of vitriol (sulphuric acid) boils (under common pressure).
	[illegible]	MERCURY boils under the common atmospheric pressure.
Measured by Daniell's Pyrometer.	[illegible]	Zinc melts.—Zinc boils at [illegible].
	800	Antimony melts. (800 *Red heat visible in the dark*,
	[illegible]	*Red heat visible in daylight*.)
	1140	Heat of a common fire.—[illegible], *[illegible]*
	[illegible]	Brass melts.—[illegible], Silver melts ([illegible]).
	[illegible]	Copper melts.—2,016, Gold melts.
	2,786	Cast Iron melts (*White-heat*)
	3,280	Greatest furnace heat measured by Daniell. (Wrought Iron and Platina did not melt.)
Not yet Measured.		Flame of the oxy-hydrogen blowpipe, Platinum melts.
		Galvanic current through air.
		Solar rays condensed by mirrors.....Gold boils.

We see by the instructive experiment mentioned at the bottom of p. 844, that every substance on the earth, however low its temperature, is constantly radiating its heat in all directions equally, and is also receiving heat in every direction except from the regions of space, or what we call the blue sky. After sunset, the supply of heat from the sun is withdrawn, but radiation still continues; and if there be no clouds to reflect back the heat, the temperature of the earth's surface soon sinks below that of the air which rests upon it, and the consequence is, a condensation of the moisture of the air by the colder earth in the form of *dew*. For the further consideration of this part of our subject we must refer to the article EVAPORATION.[1]

It appears from Mr. Joule's Experiments, undertaken with a view to determine the mechanical equivalent of heat,—1st, that the quantity of heat produced by the friction of bodies, whether solid or liquid, is always proportional to the quantity of force expended; and, 2nd, that the quantity of heat capable of increasing the temperature of a pound of water (weighed in vacuo, and taken at between 55° and 60°) by 1° Fahr., requires for its evolution the expenditure of a mechanical force represented by the fall of 772 lbs. through a space of 1 foot.

HEAVY SPAR, a term applied to native sulphate of barytes on account of its great weight, the sp. gr. being from 4·41 to 4·67. See BARIUM.

HECKLE. See FLAX.

HELIOSTAT, (from *ἥλιος* the sun, and the root *στα*, to put or place,) an instrument, by means of which a solar ray admitted into a darkened room may be fixed in any desired position for optical experiments. It consists of a plain metallic mirror, provided with a vertical and horizontal movement, and of a clock, the index of which moves in a plane parallel to that of the equinoctial. The extremity of the index is connected with the hinder part of the mirror by means of a long cylindrical rod adjusted perpendicularly to the mirrror.

HELIOTROPE, or BLOODSTONE. See AGATE.

HEMATINE or HÆMATEINE. See LOGWOOD.

HEMP. A plant supplying a valuable and efficient material for cordage, and likewise every description of *canvas*. The latter word appears to be a corruption of *cannabis*, the Latin name of the genus to which hemp belongs. *Cannabis sativa*, or common hemp, has been cultivated in the East from a remote period, but not for its valuable fibres. The Orientals prepare from it an intoxicating liquor called *bang*, which serves both in India and Egypt as a substitute for malt-liquor. Hemp is also supposed to be indigenous in Europe, for so long ago as the time of Herodotus it was said to be growing wild in the country of the Scythians, and also to be cultivated for the fabrication of hempen cloth. In Russia and Poland the cultivation of hemp is carefully attended to at the present day and the produce is of great importance in a commercial point of view: it is also cultivated in Italy, in the British isles, and elsewhere. America fosters this plant, but not to an extent to supersede importation. The hemp produced in England and Ireland is of excellent quality, but its cultivation has not been found generally profitable, and accordingly has been limited to a few districts.

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[1] This article is abridged from the Editor's "Introduction to the Study of Natural Philosophy," second edit. 1851. Published in Weale's Rudimentary Series. See APPENDIX.

The stem of this plant, as of flax, consists essentially of a woody core, surrounded by a sheath of fibrous matter, which is held together by a kind of vegetable glue. The appearance and growth of the two plants are, however, very dissimilar. Hemp belongs to the same natural tribe as the nettle, and has the coarseness of growth which characterises its relatives. It is an annual plant, some 5 or 6 feet high, with a rough and strong stalk, on which large leaves grow in pairs, on opposite footstalks, with two leaflets at their base. Some of the plants are flower-bearing, others fruit-bearing; the former being taller, more slender, and having finer and more elastic fibres than the latter. See Fig. 1138. It is impossible to distinguish this difference until the plants are nearly full grown, or to calculate on the preponderance of one or the other sort of hemp in the crop. The proportion of each, however, is generally pretty equal. On a rich moist soil hemp becomes coarse, but strong in the fibre; on a poor soil, it is slender and fine. If it be required for cables, hawsers, and other heavy rigging, it can scarcely have too rich a soil or too much manure; if it be wanted for weaving purposes, it should be sown broadcast on a poor soil. When sown and raked, or harrowed, it requires great vigilance to preserve it from birds, who have the utmost avidity for hempseed. It is a remarkable property of this crop that it scarcely requires weeding; on the contrary, the growing of hemp on a rank weedy soil is said effectually to cleanse it, so completely does it occupy the soil to the exclusion of all other vegetation.

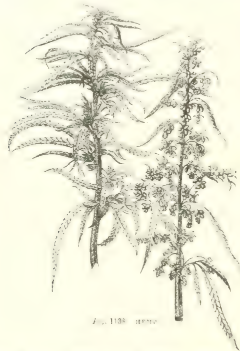

Fig. 1138. HEMP.

In little more than three months the flower-bearing hemp has arrived at maturity, its flower fades, the farina falls, and the stem becomes yellowish. The fruit-bearing plants are not perfected until three or four weeks later, on which account there are frequently two separate gatherings of the crop. These are effected by pulling up the plants, cutting off the leaves, flowers and roots, and tying up the stalks in bundles. The next process is *retting* or *rotting* in water for the purpose of dissolving the vegetable glue which holds the fibres together. There are many objections to this practice, which is slow, uncertain, unwholesome and injurious to the fibre. "Hemp," says Professor Solly, "though from its coarser fibre less liable than flax to be injured by retting, is unquestionably often greatly deteriorated by the fermentation to which it is exposed; indeed in the old methods of preparing hemp, it was never considered to be retted enough until it was evidently injured. In illustration of this rather strange statement, let me refer you to Antill's observations on dressing hemp: he says, 'To know whether the hemp is rotted enough, take a handful out of the middle row, and try with both your hands to snap it asunder; if it break easily it is rotted enough, but if it yet appear pretty strong, it is not, and must lie longer till it breaks with ease.'" Some improvements have been made in the process of retting within the last few years, more particularly as it applies to flax, where warm water is used to expedite the operation; but the larger proportion of hemp-growers continue on the old methods to rot the stalks, either by letting them lie buried in snow, or exposed to the air and dew, or steeped in the water of ponds, or in that of running streams. The last named is mostly prohibited, on account of the poisonous properties attributed to the plant during putrefaction. The mode of retting as practised in Livonia seems one of the least obnoxious. Five or six basins about two feet deep are dug at different levels, where a fall of clear water is to be had; these basins are divided by slight banks made of clay, but communicate by means of a small hole in each basin, which can be plugged when required. The hemp is steeped in the lowest basin for two or three days, then in the next higher, and so on up to the highest, fresh plants being put in below as soon as there is room for them, the water in the top basin being at the same time renewed, and the holes unstopped so that a change of water takes place at the same time in all the basins.

When fermentation has proceeded far enough, the stalks are dried in the sun, or in ovens, or in warm rooms. They are then broken at a hand-break, or by mills, in the same way as flax, and the after processes of scutching and heckling are likewise similar.

The hemp trade of Petersburg figures largely in the commerce of that city. The hemp is brought to Petersburg from the interior beyond Moscow by water, and its quality varies greatly, according to the country in which it is produced. The great arrivals are in the spring and summer, and the work of sorting it into qualities and making it up into bundles is performed by sworn agents called *brackers*, and by binders appointed by the government. To every bundle of hemp thus assorted there is attached a ticket with the names of the selector, binder and owner, and the date and year. Every bundle has also a piece of lead affixed to it, on which is stamped the selector's name on one side, and the sort of hemp and the time of selection on the other. The external marks of good hemp are its being of an equal green colour and free from spills; but its quality is further tested by the strength of the fibre, which should be fine, long, and thin. The best quality is called *clean hemp*, or first; the next, *out-shot hemp*, or seconds; then comes *half-clean hemp*, or thirds; and lastly, *hemp codilla*. This last is merely the part picked out in cleaning the other sorts. Of the first three sorts there were formerly shipped at Petersburg every year about two million poods (63 poods = 1 ton), but the trade suffered greatly during the late war, and has not yet recovered.

In shipping hemp at Petersburg care is taken to preserve it from wet, which would cause it to ferment afresh, and become totally spoiled. Every vessel taking in either hemp or flax is therefore provided with mats for its preservation. The hemp is forced into the hold of the vessel by means of winches, and thus made to occupy less room. Warehouses have been built in Petersburg for housing hemp.

A very fine quality of Russian hemp is obtained from Riga, being brought down the river Dwina, from the interior, about the middle of May. This fetches a higher price than hemp from Petersburg. As a general rule, the prices of Russian hemp are highest in May, June, July, and the early part of August. In the month of September bargains may be obtained, many of the less opulent hemp-merchants being willing to sell their remaining stock at some roubles below the market price, in order that they may clear all out, and return to their own country to make new purchases for the ensuing year.

Our imports are entered as "Hemp (dressed and undressed) and tow or codilla of Hemp."

	1859. Cwts.	1860. Cwts.	1861. Cwts.
From Russia	[illegible]	[illegible]	[illegible]
„ Austrian Territories .	106,164	[illegible]	[illegible]
„ British East Indies . .	51,012	16,570	[illegible]
„ Philippine Islands . .	172,577	[illegible]	[illegible]
„ Other countries . . .	26,595	[illegible]	11,475
	1,088,240	[illegible]	[illegible]
Jute, and other vegetable substances of the nature of hemp	1,071,731	[illegible]	[illegible]

This extraordinary development of the trade in Manilla and Indian hemps, jute, &c., of late years is one of the consequences of the war with Russia. Manilla hemp, or *white rope*, is obtained from the bark or epidermis of a species of wild banana (*Musa textilis*), which grows abundantly in the Spice Islands. Whole forests of this kind of banana exist in Mindaneo, one of the Philippines, and from it the natives fabricate both cordage and cloth. Indian hemp, or Sunn, (*Crotolarea juncea*,) is the fibre of a very different plant from our hemp, grown in different parts of Hindostan. Jute consists of the fibres of two plants, of the genus *Corchorus*, extensively cultivated in Bengal. It is much used in the great manufactures of Dundee, for the coarse fabrics used for bagging, &c.

English hemp, though well qualified by its strength and excellence for the manufacture of sailcloth and cordage, is seldom used for that purpose; but is principally made into the finer descriptions of hempen cloth, some of which can scarcely be distinguished, after they have become white by repeated use, from Irish linen. Excellent *huckaback* is made of it, for towels and common tablecloths; and a coarse cloth of great strength adapted for the shirting and sheeting used by labouring men. There are also varieties of superior quality and fineness, preferred by some gentlemen on account of their great strength and warmth, and possessing, besides these advantages, that of improving in colour the longer they are worn, whereas the reverse is the case with every other kind of linen.

HIDE, see LEATHER.

HINGE,—a joint of wrought-iron, cast-iron or brass, on which doors, lids, gates, shutters, &c. are made to swing, fold, open, or shut up. The usual form is that of two leaves, each furnished with a projecting segment or segments of a hollow cylinder, which fit together and admit of being united by a central pin. In applying this joint, one leaf is screwed to the door, and the other to the door-post, as is well known. The chief varieties are noticed in Hebert's Engineers' and Mechanics' Encyclopædia, as consisting of "*cross-garnets*, made in the form of the letter T, for gates and outhouse doors, from 6 to 36 inches long; and a nearly similar kind made with long straps and hooks to fix in the stiles, to enable the gates or doors to be lifted off their hinges at pleasure. Those used in common for the doors of apartments are termed *butts*, of which there are many varieties; those used for shutters are called *back flaps*: similar hinges are used for the joints of bedsteads, and very nearly the same kind for Pembroke and other tables; another sort called H and H_ hinges, from their resemblance to these letters, are extensively employed for common purposes. There are also many other sorts, distinguished by appellations that designate their uses, and are too numerous to mention." The chief manufactories are at Birmingham, Wolverhampton, Tipton, and several parts of Staffordshire; the best wrought-iron hinges are made in Lancashire, and the heavier sort at Newcastle: there are also some excellent makers in London.

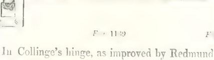

Fig. 1139

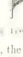

Fig. 1140

In Collinge's hinge, as improved by Redmund, the bearing pin consists of the conical stem *h* and the conical top *i*, Fig. 1140, corresponding with the bearing socket of the hinge, Fig. 1139. Over this is a hollow cap fixed to the other limb of the hinge, the two parts fitting accurately; this cavity is for the reception of oil, and there is a small perforation to conduct it between the two surfaces, which work with great truth and freedom. This form is well adapted for turnpike gates.

Mr. Redmund's hinges are termed *rising butts;* that is, the hollow cylinder attached to the leaves, instead of being divided at right angles to the axis or pin *b*, Fig. 1142, are divided by spiral, or rather helical lines, so that when the door is opened it is lifted up from the floor by the rubbing surfaces moving in a helical line upwards, so that although the door may shut close down upon the carpet, it rises when opened to a sufficient height to clear the carpet. Another advantage of this kind of hinge is, that the weight of the door acting upon the inclined rubbing surfaces causes it to close of itself; but provision is also made for causing the door to stand wide open when required: this is done by cutting away a portion of the helical curves, so as to form two horizontal planes which become opposed to each other when the door is opened to about an angle of 90°, or so as to form a right angle with its position when shut. By this arrangement, therefore, the door will close of itself when not thrown open more than 50° or 60°, which is as much as is required for free passage, but it will stand wide open if pushed as far as 90°. In this position a slight pull will cause the horizontal plane to slide off its support, and the door then returns by its descent on the helix. By the introduction of a small spring the door may be made to shut to closely when opened only a very little way. Hinges supplied with more powerful springs are used for the swing doors of public offices, &c., which are contrived so as to open either way, and to return quickly to their shut-to position.

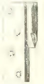

Fig. 1141.

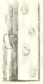

Fig. 1142.

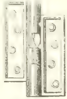

Fig. 1143.

In connexion with spring hinges, we may mention Mr. Hebert's contrivance for securing outside shutters when thrown open. Fig. 1144, is the ordinary hinge shut, and Fig. 1145, the same open. A square hole is cut out at *a*, and a semicircular piece of iron *a b* riveted into it; a portion of the iron being split so as to form a spring, the extremity is turned upwards to form a stop, as at *c*. On opening the hinge the flap *b* passes over the arc, pressing on the spring, and when arrived at the stop *c*, it has passed the spring and is completely open with the shutter fastened flat against the wall. When it is required to close the shutter, the spring, which is close to the window, is to be pressed down to allow the flap *b* to come back over it; and when shut it appears as in Fig. 1144. This contrivance is only wanted on the lower hinge; it can be added for the additional cost of 6*d*. on a pair of hinges, and supersedes the troublesome turnbuckle, which fails to hold the shutter securely.

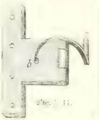

Fig. 1144.

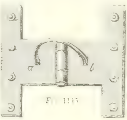

Fig. 1145.

Whitechurch's patent hinge is so contrived as to allow doors, windows, &c. to be opened either to the right or the left hand. Nettlefold's hinge for book cases consists of a brass plate *a*, Fig. 1146, which is screwed to an upright partition, projecting from *a*: and cast therewith are the parts *b b*, the extremities of which are rounded off and perforated to receive the centre pin, which passes through them and the joint of the common butt hinge *c*, to the flaps of which are screwed the doors *d* and *e*. It will be seen that the door *e* folds back quite level with the bookshelves, and that the door *d* folds close against *e*, so as to be parallel with it and quite out of the way, so that the books close to the hinge can be taken out and put in without first disturbing the adjacent books, which is the case by the usual method of hanging doors to libraries. Now it is obvious that when the door *d* is turned back the contrary way, both doors are shut and lie flush and close, and that the door *e* may in like manner be folded over *d*. Thus great convenience is afforded by a single hinge, instead of two hinges, and the necessity for an additional hanging style is avoided.

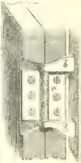

Fig. 1146.

A number of patents have been taken out of late years for improvements in the construction or manufacture of hinges. In Johnston's patent (sealed July 1839) the eyes of the hinge are formed out of one piece with the hinge plate, by forcing that portion of the metal of which they are composed into dies so shaped or formed as to turn over the metal into the form of eyes. For example, two plates of malleable or ductile metal are first stamped out, as shown in Fig. 1147: the projecting pieces or tongues are then forced into and against the concavity of the die, Fig. 1148, by which the tongues conforming to its curve become bent flatwise in their whole length, or so as to bring

Fig. 1147.

Fig. 1148.

Fig. 1149.

the ends over to their own surface or to that of the plate to which they belong. See Fig. 1149.

Wilkes's patent (1840) is for manufacturing hinges by casting the two sides or flaps, and hinge joint thereto, at one time, on to a suitable axis.

Horne's patent (1840) is for an improved method of preparing the strips or plates of iron for hinges, so that the fibres of the metal shall be laid or placed crosswise of the hinge; secondly, for an improvement in making the joint, and for countersinking the screw-holes by means of coned dies.

Redmund's patent (1842) is for the construction of each of the flaps and its knuckle-joint-piece of rising hinges of one piece or casting; for a method of casting gate or such like hinges in such a manner as to obtain strength with lightness; also for a mode of constructing spring hinges, the knuckle-joints being made hollow to receive a compound coiled spring within a hollow axis. Instead of coiling a single wire into a spring, as is usually done, the inventor coils two, three or more wires side by side into a spring, by which means he obtains powerful springs in the same compass as that occupied by a spring of like diameter of one coil of wire, and which would of course be of much less strength. Figs. 1150, 1151, and 1152 give different views of this hinge: *j*, *k* are the two flaps; *l* a spring of two wires placed within the tube *m*, such tube being the pin or axis of the knuckle-joints of the hinge; *n* is a pin or stem within the spring, and fastened in the two ends of the caps of the knuckle-joints. The caps *o o*, have each a two or more threaded female screw formed therein to correspond with the spring used, and according as these caps are screwed up tightly so will the pressure of the spring be regulated, there being ratchet teeth to hold the caps, which allow them to be turned each in one direction, but resist their turning back. The last part of the patent is for a door hinge, which opens in either direction. Fig. 1153 shows the plan of this hinge, and Fig. 1154 the axis for carrying the door. On this axis is fixed the cam p', in which at q^2 is a recess for the reception of the pressing lever. When the door is shut, q is a lever moving on an axis at q', and it carries a friction-roller q^2; a constant pressure is kept up against this lever by the springs *r r*.

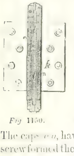

Fig 1150.

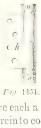

Fig 1151.

Fig. 1152.

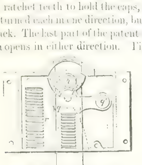

Fig 1153.

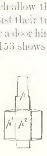

Fig 1154.

Gollop's patent (January 1845) is for improvements in spring hinges and spring roller blinds. Instead of cylindrical springs of wire, a coiled flat bar or ribbon of steel is used. The arrangements are ingenious, and admit of extensive application.

Wilkes's patent (April 1845) is for forming the knuckle-joints of hinges without flaps by casting or otherwise separately; and then having combined them on axes and placed them in suitable moulds, to cause the flaps to be cast thereto.

Boydell's patent (November 1845) is, 1, for a mode of casting iron and brass hinges, the pivots or axes of the knuckles of the hinges being of one piece with one of the flaps of a hinge; 2, for a mode of casting brass hinges where separate pivots or axes are applied after the flaps of a hinge are cast; 3, for a mode of making cast hinges, casting the flaps of hinges several at one time, and in one piece, and then dividing them afterwards; 4, for a mode of annealing hinges.

HIRCINE, a peculiar fat obtained from the goat.

HONE, or HONE SLATES, a term applied to various slaty stones, which are used in straight slabs for whetting or sharpening the edges of tools after they have been ground on revolving grindstones. Mr. Knight, in his paper in the 50th volume of the Transactions of the Society of Arts, has enumerated the principal varieties. These are as follows:—1. *Norway ragstone*, the coarsest variety of the hone slates. It is largely imported from Norway, in the form of square prisms, from 9 to 12 inches long, and 1 to 2 inches in diameter. It gives a finer edge than the sandstones, and is in very general use. 2. *Charnley Forest stone* is one of the best substitutes for the Turkey oil-stone, and is used by joiners and others for giving a fine edge to various tools, and also to penknives. It is found in Charnwood Forest, near Mount Sorrel, in Leicestershire. The best variety is said to come from the Whittle Hill quarry, the other stones in the neighbourhood being more *pany*, *i. e.* presenting hard places. 3. *Ayr stone*, *Scotch stone*, or *snake stone*, is used for polishing marble and copper plates; but the harder varieties are used as whetstones. These stones are always kept damp or even wet, to prevent them from becoming hard. 4. *Idwall* or *Welsh oil stone* is similar to No. 2, but generally harder. It is obtained from the vicinity of Llyn Idwall, in the Snowdon district of North Wales, and is more generally used for small articles of cutlery than No. 2. 5. *Devonshire oil-stone*, from the neighbourhood of Tavistock, is described as an excellent, but little known, variety, for sharpening all kinds of thin-edged broad instruments, as plane-irons, chisels, &c. 6. *Cutler's green stone*, from the Snowdon mountains of North Wales, is of so hard and close a texture as to be applicable only to the purposes of cutlers and instrument makers, for giving the last edge to the lancet and other delicate surgical instruments. 7. *German Razor hone* is known and esteemed throughout Europe as the best whetstone for the finer descriptions of cutlery. It is almost exclusively used for razors; for being very soft, it is cut by an instrument applied at an angle, instead of being laid down flat as the razor is. This stone is obtained from the slate mountains near Ratisbon, where it occurs in the form of a yellow vein running into the blue slate, sometimes not more than an inch in thickness, and varying to 12, and in some places 18 inches; from whence it is quarried, and sawed into thin slabs, which are usually cemented into a similar slab of the slate to serve as a support. That which is obtained from the "old rock," or lowest part of the vein, is esteemed the best. 8. *Blue polishing stone* is a dark slate of uniform character, and not laminated in appearance. It is used by jewellers, clockmakers, and other workers in silver and metal, for polishing off their work. It is cut into lengths of about 6 inches, and from ¼ inch to 1 inch or more wide, and then packed into small bundles containing from 6 to 16 in each, and secured by withes of osier, in which state it is imported for use. 9. *Grey polishing stone* is similar in properties and uses to the *blue*, but somewhat coarser in texture, and its colours are paler. It is obtained from the same locality. 10. *Welsh clearing-stone* is a soft variety of hone slate cut in a circular form, and used by curriers for giving a fine smooth edge to their broad straight-edged knives used for dressing leather. 11. *Peruvian hone* has been recently introduced as a whetstone, and is said to come from South America. It cuts freely with oil or with water, and is suitable for sharpening large tools that do not require a very fine edge. 12. *Arkansas stone*, from North America, is of unequal texture, and cuts slowly. 13. *Bohemian stones* are imported from Germany, and are used by jewellers in the same way as Nos. 8 and 9, for polishing small work, such as the settings around gems. They cut well, and keep a good point for small work.

In addition to the above, we may here notice the *Turkey oil-stone*, although, from the absence of lamellar or schistose structure, it can scarcely be considered as a hone slate. Mr. Holtzapffel remarks, that "as a whetstone it surpasses every other known substance, and possesses in an eminent degree the property of abrading the hardest steel, and is at the same time of so compact and close a nature as to resist the pressure necessary for sharpening a graver or other small instrument of that description. Little more is known of its natural history, than that it is found in the interior of Asia Minor, and brought down to Smyrna for sale. The white and black varieties of Turkey oil-stone differ but little in their general characters; the black is, however, somewhat harder, and is imported in larger pieces than the white. The rough irregular pieces of oil-stone scarcely ever exceed about 3 inches square and 10 inches long, and are generally about one-third smaller. When cut into rectangular forms, it is done with the lapidary's slitting-mill and diamond powder. The blocks are then rubbed smooth with sand or emery on an iron plate. The piece of oil-stone is generally inlaid in a block of wood, in which it is cemented with the putty used by glaziers, and to avoid the deposition of dust, a wooden lid is usually added. The lid is sometimes covered with a thick piece of buff leather, which serves to absorb the oil from the tool, and is used in the manner of a razor-strop." Sperm or neat's-foot oil, or an oil not disposed to thicken, should be used.

Many persons find it difficult to use the hone in setting their razors, and are quite unable to produce the exquisite edge which cutlers give. For such persons, Mr. Fayrer's swing hone may be useful. It consists of a flat and parallel slip of brass, *a*, Fig. 1155, formed like a hone, but with pivots at the end, by which it is mounted in two notches, *d d*, of a frame, *c c*, so as to swing and accommodate itself to the angle at which the razor or other instrument is applied to it. *e e* are two boxes, one to hold a coarse, and the other a fine, powder. One side of the brass, marked R, is first used with fine oil-stone powder and oil, afterwards the other side with pulverized water-of-Ayr-stone and oil, and the razor-strop is then resorted to.

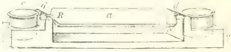

Fig. 1155.

Small pieces of this stone are cut into slips of different forms for the use of the lapidary and others. Oil-stone powder is also used for grinding together the brass or gun-metal fittings of mathematical instruments; and this powder is preferred to pumice-stone powder for polishing superior brass works.

The following are the analyses of a few polishing stones:—

	Alumina.	[illegible]	Lime.	Iron.	Water.	Magnesia.	Carbonic Acid.
Polishing slate	4·0	[illegible]	[illegible]	[illegible]	[illegible]		
—	7·0	[illegible]	1·25	[illegible]	10·0	1·5	
Bohemian stone	1·0	[illegible]	1·0	4·[illegible]	14·0		
Turkey hone	[illegible]	72·0	[illegible]				[illegible]

In our article CUTLERY, we referred the setting of razors to the present article: we will therefore conclude with a few details on this subject. A razor may be defective from being *notched*, from having a *wire edge*, or a *blunt obtuse edge*. Notches arise from brittleness of the metal, occasioned by overheating in the forging or hardening. There is no remedy for this defect, unless, indeed, it has merely been left too hard in the tempering, when it may, perhaps, be remedied by tempering a little lower than at first. The wire edge in a new razor arises from the use of the glazers and polishers used in the manufacture. As these revolve away from, and not towards the edge, they always leave a thin filmy edge. The wire edge may also occur from the excessive use of the hone, "as when the two faces of the wedge are rubbed away beyond that point at which they first meet, a slender film of steel begins to form, because the extreme edge is then so thin, that it bends away from the hone instead of being rubbed off." The blunt obtuse edge is often occasioned by an excessive use of the strop, or after grinding, the hone has not been sufficiently used. The rounded edge may occur from the use of a soft strop; the leather against the edge being indented, rises at an abrupt angle, and injures the keenness of the blade.

The whetstones used in setting razors should be perfectly flat on the face: they should be always supplied with oil, and be kept clean. In a new razor, or an old one just ground, the Charnley forest stone is used for striking off the wire edge. The Turkey oil-stone and the green hone, or Welsh hone, are also used; but the yellow German hone is to be preferred to all. Slabs of hæmatite iron ore are also occasionally employed for giving the final edge.

In striking off the wire edge "the blade is grasped in the right hand by its tang, and near to the cutting part, and is placed square across the one end of the stone, but tilted about 10° or 20°, and is then swept forward along the stone, edge foremost, in a circular arc, so as to act on the entire edge: each side in general receives only one stroke, and this produces a comparatively obtuse edge, measuring from 40° to 60°. Should this fail to remove the wiry edge, the blade is placed perpendicularly upon, and drawn with a little pressure across, a strip of horn, (generally a spoiled razor handle,) which is fixed down to the bench, the friction of the horn against the edge generally suffices entirely to remove the wiry film, otherwise the blade is struck once more on each side along the stone. Should the film of steel be left in the stone, it is removed before another blade is applied." The razor is then set on the German hone. It is held as before, but placed quite flat down so as to touch on the back and edge. "Some prefer a long sweeping stroke backwards and forwards, others prefer small circular or elliptical strokes, and others a short zigzag movement, but all gradually work from heel to point, or draw the razor forward so as to act on all parts alike, and most persons lift the razor endways towards the conclusion, allowing its point still to rest on the hone with the view of sharpening the circular end of the blade." The razor must be turned over at short intervals so as to whet it upon its opposite sides alternately; but it is usual "to conclude the process by sweeping the razor edge foremost once on each side steadily along the hone, as if in shaving off a thin slice of the hone: this lessens the disposition to the wire edge." The process must be continued until the new facets, constituting the wedge of 17° to 20°, exactly meet at the extremity of the more obtuse angle given by the striking off. Should the wiry film still form, it must be removed by drawing the blade across the slip of horn, and continue the whetting for shorter periods on each side. If the film is very minute, some persons leave it to be removed by the strop; but the hone must not be given up until the notches are no longer perceptible, and the edge, when viewed edgeways, does not present any visible thickness or width, but only the meeting of the two sides of the blade. The razor may now be slightly stropped, drawing it backwards from heel to point. The strop should have a hard surface, and only a very moderate quantity of abrasive matter; for if soft, and with a large quantity of dressing, the edge of the razor is very liable to be turned round. Mr. Holtzapffel recommends for the razor-strop a fine smooth surface of calf-skin, with the grained or hair-side outwards, pasted or glued down flat on a slip of wood. Almost any extremely fine powder, mixed with a little grease and wax, will do for the dressing, such as impalpably fine emery, crocus, natural and artificial specular iron ore, black lead, or the charcoal of wheat straw. The puffing advertisements and affected mystery of some strop-makers are unworthy the character of honest tradesmen. One side of the strop should be left plain for the finishing stroke, and the sheath, intended to keep the strop clean when not in use, should always be put on the same way, to prevent any of the dressing from being carried over to the plain side.

It is recommended by some to strop the razor immediately after use; others, on the contrary, advise that it should simply be wiped dry on clean wash-leather, or a soft towel, and not stropped until it is used again. We have tried both methods, and prefer the former. Although it is likely that many of the rules respecting razors are dictated as much by fancy as by reason, yet there does seem to be some grounds for the preference. In the operation of shaving we would recommend a cold lather for the face, the usual supply of hot water to be merely used for dipping the razor, which may be done once or twice during shaving, and again just before stropping. Now the effect of the dipping is to raise the temperature of the blade, and cause the edge to yield readily to the strop; then, during the repose of 24 hours, it cools down, and settles into that condition of edge which was imparted to it by the final stropping; and if this be skilfully and judiciously done, the razor is in prime condition when the time for shaving again comes round. If, on the contrary, the razor be dipped into hot water and stropped just before being used, the effect is too abrupt and sudden to allow of those molecular changes which we may suppose to take place on allowing the metal time to adjust itself on cooling down. But whatever course be adopted, one thing is certain—unless the strop be used with great moderation and caution, it is always likely to do more harm than good.

After the razor has been frequently set, it becomes so wide in the bevil or facet as to require re-grinding to thin it away. The cutler tries the keenness of the edge by making a faint incision in the thick skin, covering the inner edge of the palm of the left hand; he also tries it upon the thumb or finger-nail, placing it in a line with the finger, and obliquely across the end of the nail, or at right angles to the finger, allowing it to rest upon the back of the nail: the nail of the third finger is considered the most sensitive. In this way a very minute notch in the edge is quite perceptible: the keenness is also judged of by the degree in which the razor hangs to the nail, the keen blade making the deeper incision, and offering a dragging but smooth resistance, while the blunt razor slides over with less penetration and drag. Mr.

Kingsbury proposes the use of a magnifier for examining the entire edge. Under a microscope of a linear power of 50 to 100 the edge presents a faintly undulating and irregular line, resembling a ripple mark. Indeed, the edge of a good razor bears this severe scrutiny much better than most of the productions of art.

HONEY. See SUGAR.

HONEY-STONE, or MELLITE, a rare mineral, found in small solitary octohedral crystals of a honey-yellow colour, among the layers of wood-coal at Artern, in Thuringia. It contains an organic acid, the mellitic, (C_4HO_4,) and is in fact itself a mellitate of alumina.

HOPS. See BEER, vol. i. p. 113.

HORDEINE. See BEER, vol. i. p. 112.

HORN. The term horn is commonly applied to any hard projecting body on the head of animals, serving as a weapon of defence; but it is strictly applicable only to a certain class of such weapons. For instance, the antlers of the stag consist entirely of bone, and have no right to the denomination "horns;" the weapons of the ox, the sheep, and the antelope, consist of a sheath of true horny material on a bony core; while the horns of the rhinoceros are wholly composed of horny matter. Bone and horn are as distinct from each other as both are from ivory; yet the three are often confounded by the application of the general term "horn" to antlers, tusks, and true horns. Besides the horns on the head of animals, there are other horny processes in the hoofs, claws, nails, &c., and there are various modifications of horn, in the scales of the armadillo, the plate-armour of the tortoise, the spines of the porcupine and hedgehog, and the quills of birds.

Horn consists principally of membranous animal matter, being a compound of coagulated albumen, gelatine, and a small portion of phosphate of lime. It has been well remarked of these proportions, "had the horns much more earth, they would be brittle like bones; had they much more gelatine, they would be soluble like jelly or glue;" as it is, they are easily convertible to the purposes of the manufacturer, by whom they are so largely used that considerable importations of horns are necessary, in addition to the supply afforded by this country.

The horns chiefly applied to manufacturing uses are those of the bull and cow, with the hoofs of those animals. Large quantities are imported from Russia, South America, and Southern Africa. The horns of the bison and buffalo are also in demand, the latter being frequently reserved, on account of their beauty, for superior purposes. The horns of the chamois and antelope are polished and used in their natural forms.

The first process in the manufacture of horn is that of detaching it from the bony core: this is done by maceration of the whole horn in water for a month or six weeks, when the membrane which attaches the horn to the core is destroyed by putrefaction, and the two become easily separable. The cores, when burnt to ashes, form the best material for the small tests or cupels employed by the assayers of gold and silver.

The tips of the horn are then sawn off, these being entirely solid, and adapted for cutlery purposes, for the button-manufacture, &c. The remainder of the horn is then either cut into short lengths, or soaked entire, according to the use to which it is to be applied. Immersion in boiling water for half an hour greatly softens the horn, but the effect is afterwards heightened by holding it in the flame of a coal or wood-fire, when it becomes exceedingly soft, and can be easily slit up the side with a knife. It is now opened by means of pincers, and spread out nearly flat. In order to obviate the risk of scorching the horn over an open fire, Mr. James employs a sort of iron mould, with a conical iron plug. These are heated at a stove to the temperature of melting lead, and the horn cut lengthways with a saw or knife is inserted in the mould. The plug is then gradually driven in with a mallet, and in about a minute the horn is softened and ready to be opened in the usual manner. The "flats," as they are called, are then inserted either between iron plates, previously heated and greased, or between wooden boards, and are subjected to a certain amount of pressure, varying according to the intended use of the horn. If it is to be used in lanterns, the pressure is continued until the substance of the horn is separable into distinct plates. These are laid singly on a board covered with bull's hide, and scraped with a draw-knife, having a wire edge. When reduced to the proper degree of thinness, they are polished, first with a woollen cloth dipped in charcoal-dust and water, then with rottenstone, and finally with horn shavings. The largest of the films of horn which come off during these processes, are often dyed and cut into various forms, when they become highly sensitive, and curl up by the mere warmth of the hand. Toys of this description were originally brought from China, hence they are commonly called Chinese sensitive leaves.

For general purposes the pressure given to horn is very moderate, especially for combs, where too much pressure causes the teeth to split. Heat and pressure applied to light-coloured horn, render it transparent; but artificial colour is given to the greater part of the articles fabricated of horn. This is easily done by boiling the horn in infusions of colouring ingredients. The rich red-brown, employed to imitate tortoiseshell, is obtained by mixing pearlash, quicklime, litharge, and a little pounded dragon's-blood, in a sufficient quantity of water. This preparation, after boiling half an hour, is applied hot to those parts of the horn which are to be coloured, and is left some time on the surface. A deeper tinge in particular parts is obtained by repeating the application. A blacker brown is produced by omitting the dragon's-blood.

For drinking-cups the horn is cut into lengths before it is softened, and when the scalding and roasting processes have been gone through, it is not slit, but placed while hot in a conical mould of wood, a conical wooden plug being also driven in, to press the horn to the true shape. When cold it is taken out of the wooden mould, and fixed by the large end to the mandril of a lathe, where it is turned and polished, and a groove formed to receive the bottom. This is cut out of a flat piece of horn by means of a crown saw, and is dropped into the horn, and forced into the groove, the horn having been previously softened before the fire, enough to admit of the necessary expansion. Contracting as it cools, the horn fixes the bottom so firmly as to make it perfectly water-tight.

For knife-handles and other works where horn requires to be moulded, the process is as follows. The horn is first cut with a saw into convenient pieces, and then heated until soft enough to be pared and shaped with a knife into somewhat of the required form. The pieces are then pressed into moulds consisting of two dies, or pieces of metal having cavities sunk in them; these cavities to be either straight, curved, twisted, or engraved in any device, according to the pattern to be produced. This mould, with the horn enclosed, is placed in a clamp worked with a powerful screw, the mould and horn having been dipped in boiling water for a few minutes previous to being subjected to its action. After 20 minutes' pressure the work is ready for finishing, which includes scraping and buffing with Trent sand and oil, and afterwards with rotten-stone and oil. Horn is sometimes used by watchmakers as a vehicle for the application of polishing powders to flat works.

The ancient uses of horn include its conversion into bows, examples of which are still found in India and China; its use as a musical instrument, (the horn of the wild bull tipped with silver, and slung in a silver chain, having been the true bugle-horn of former times;) its employment in windows before the discovery of glass, and its conversion to purposes of defence, a complete suit of scale armour made of horn having been seen and described by Mr. Aikin, to whose Lecture on Horn, delivered before the Society of Arts, and printed in their Transactions, vol. lii., we are indebted for many of the above particulars.

HORNBLENDE, an essential constituent of certain rocks, as sienite, trap, and hornblende slate. It occurs in black and greenish black crystals and massive specimens: often in slender crystallizations, like actinolite, and in short thick crystals. Its dark colour is due to oxide of iron. Its composition is, silica 48·8, magnesia 13·6, lime 10·2, alumina 11·5, protoxide of iron 3·5, protoxide of manganese 1·15, hydrofluoric acid and water 2·2.

HORN LEAD. See LEAD.

HORN SILVER. See SILVER.

HORN STONE. A variety of rhomboidal quartz, used for grinding flints in pottery mills. It is called *chert* in Derbyshire. [See POTTERY and PORCELAIN.]

HOROLOGY, (from ὥρα, an hour, and λέγειν, to tell,) is that branch of the useful arts which describes the action of the various machines used for the purpose of measuring time.

It is not easy to give a good definition of time. According to Locke it is "the consideration of duration as set out by certain periods, and marked by certain measures or epochs." According to Aristotle "our conception of time originates in that of motion; and particularly in those regular and equable motions carried on in the heavens; the parts of which, from their perfect similarity to each other, are correct measures of the continuous and successive quantity called *time*, with which they are conceived to coexist. Time, therefore, may be defined—the perceived number of successive movements."

There is no doubt that the regular periodical movements of the heavenly bodies gave rise to the measurement of time and the present method of dividing it. The space between the rising and setting of the sun has always been called a *day*, and that between the setting and rising of the bright luminary, a *night*. The moment the sun attains his greatest altitude is called *noon* for that day; and the time from one noon to the next is called a *solar day*. These effects are produced, not by the motion of the sun, but by that of the earth: the circumference of the latter is divided into 360°, so that by turning on its axis each of these degrees is brought to the meridian once in 24 hours, and $\frac{360^\circ}{24} = 15$: hence, as 15° pass under the sun during each hour, 15° of longitude mark 1 hour of time. Berlin is nearly 15° to the east of London, so that it is almost 1 o'clock in that city when it is 12 in London.[1] The space of time between two appearances of a fixed star in the same spot, with reference to some terrestrial object, is the period of the earth's actual revolution, without reference to the sun, and is called a *sidereal day*. This is divided into 24 equal parts, called *hours*; an hour into 60 equal parts, called *minutes*; and a minute into 60 *seconds*. The year, or one revolution of the earth round the sun, is divided into 365 equal parts or days, and forms what is called *mean* time: whilst time, as naturally divided by the apparent motion of the sun, is called *true* or *apparent* time.

The earliest instruments invented for the purpose of measuring time were *sun-dials*, and *Clepsydræ*. The principle upon which sun-dials are constructed may be readily understood by supposing the earth to be a transparent sphere, Fig. 1156, with 24 equidistant circles *a*, *b*, *c*, *d*, &c. marked upon it, all passing through the poles: then, as the earth turned round upon its axis N S in its daily motion, each circle would pass in succession under the sun, or, in other words, the sun would be in the *plane* of each circle; and as the axis of the earth is in the plane of all these circles, if such axis were represented by an opaque body, such as a rod of metal, its shadow would be cast on the concave half of each circle in succession at the end of every hour, or the 24th part of each revolution. But as the distance of the sun may be regarded as indefinitely great when compared with the size of the earth, any small transparent globe, with hour-circles marked upon it, passing through the poles, and with its axis parallel to the axis of the earth, would, if made to revolve regularly in 24 hours, present the same appearances as the earth on the above supposition: the shadow of the opaque axis N S would fall in succession upon the hour-circles. Now if this small globe be cut by a plane, A B, passing through its centre parallel to the horizon of the place where the experiment is being conducted, and straight lines be drawn from the centre of the sphere to those points of the hour-circles cut by the horizontal plane; the shadow of the half axis above such plane will fall on those lines in succession every hour. In the construction of a sun-dial these lines are drawn by simple geometrical rules upon a flat surface supposed to represent the cutting plane A B; and a piece of metal, called a *gnomon*, with a sharp edge, called the *style*, is fixed on the surface, so that this style shall be truly parallel with the axis of the earth at the place of observation, then the shadow of this edge moves from one line to another in an hour. This forms the *horizontal sun-dial*. A *vertical* dial for fixing against an upright wall may be formed by cutting the globe with a vertical plane, C D, instead of the horizontal one, A B; in which case the planes of the circles will cut the upright plane in straight lines radiating from the centre of the sphere or of the circle; and the *lower* half of the axis will become the style of the dial.

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[1] This will explain some of the apparently marvellous statements which we see in the newspapers respecting messages transmitted by the electric telegraph. Thus, if a message dated 1 o'clock were sent from Berlin to London, and 30 minutes were occupied in its transmission, it would be received in London at 12·30, or half an hour by the clock before it had left Berlin.

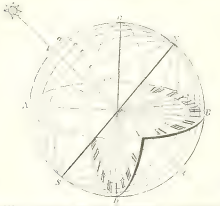

FIG. 11[illegible]—PRINCIPLE OF THE HORIZONTAL AND VERTICAL SUN-DIAL.

The word *clepsydra* is from the Greek **κλέπτω**, to steal, and ὕδωρ, water, as indicating that the course of time was marked by the *stealthy* flow of water. If a vessel of water be kept full by a stream running into it, and a hole be made near the bottom, the water will flow from the hole and fill a second vessel at a uniform rate; and this second vessel may have its sides graduated, or carry a floating index pointing to a graduated plate divided into hours, and even minutes, provided the index rise fast enough to distinguish them. When the index arrived at the top it might be made to open a valve, let out the water, and descending to the bottom close the valve, and again commence its ascent: if it were contrived that this should take place every 12 hours, it would form a self-acting clock, requiring no aid except from the stream. But if a vessel be filled and graduated according to the rate at which water flows out, which is not uniform, but varies as the square root of the height above the hole at which it stands, this will also serve for a clock until the vessel is empty.

Hollow cups, with a hole in the bottom, were sometimes used to measure time: one of these being floated upon water would gradually fill and sink in an ascertained period. The burning of a *candle* or portions thereof also served the purpose of indicating divisions of time. *Sand* is in one respect preferable to water for measuring time: it flows through an orifice with very nearly equal velocity, because the pressure among its particles is not transmitted in all directions, as in the case of water. The *sand-glass* is so contrived, that a quantity of sand shall flow from one bulb of glass into another through a short tube or orifice connecting the two, in an hour, half-an-hour, or any other portion of time, and at the end of one period, another can be marked simply by inverting the glass.

All these contrivances for marking the course of time are so very inferior to the clock, that upon its introduction they were either superseded or retained as ornaments or curiosities. The invention of the clock is of much later date than some writers have supposed; for although the term *horologium* is met with earlier than the middle of the 14th century, the period assigned for the invention, that term was probably applied to all instruments used for marking the progress of time. The first clock is said to have been erected at Bologna in 1356. In 1364, Henry de Wyck, or Henri de Vic, a German artist, placed a clock in the tower of the palace of Charles V. The introduction of clock-work into England was probably in 1368, when Edward III. granted protection to three Dutch horologiers, who had been invited from Delft. About 1370 a clock was erected at Strasburg; about the same period Courtray had a clock, which was removed by the Duke of Burgundy in 1382. There was a clock at Spire in 1395; at Nüremberg in 1462; at Auxerre in 1483; and at Venice in 1497. By the end of the 15th century clocks were not uncommon in private families on the continent, and it is probable also that they had become general in England; for Chaucer uses the terms "clock" and "abbey orloge," in the way of familiar illustration. According to Berthoud, the clock, such as that erected by Henry de Wyck, is not the invention of one man, but of many men at different periods, and the following may be regarded as the principal steps in the invention:—1. The use of *wheel-work*, which was known and applied in the time of Archimedes. 2. A *weight*, used as a maintaining-power: this would probably be accompanied by a *fly* to regulate the velocity. 3. The *ratchet-wheel* and *click*, for winding up the weight, without detaching the teeth of the great or main wheel from those of the pinion in which they were engaged. 4. The regulation by a fly being variable according to the varying density of the atmosphere, &c. would lead to the invention of the alternating motion of the *balance*, and this would require an *escapement* of some kind. 5. These last two inventions would induce great regularity in the motions of the wheelwork, and would have suggested the *dial-plate* with a single *hour-hand* or *pointer*; answering, in fact, to the sun-dial plate and the gnomon; the *minute-hand* was a later contrivance, and the *second-hand* still more recent. 6. The *striking-part*, to inform persons at a distance of the hour. 7. The *alarum*, or *alarm*, originally invented for the purpose of arousing the priest to his morning devotions.

Such appear to be the successive steps by which the clock attained a considerable degree of efficiency as a time-measurer. All great inventions are advanced towards perfection by a similar combination of the labours of many minds, and it may be taken for granted that De Wyck's clock was no exception to the general rule. One of the first applications of the clock was for astronomical observations, and we find that some of the most important improvements in clock-work are due to astronomers.

It is uncertain at what period the clock was made portable; but as early as 1530 it was proposed by Gemma Frisius to use a portable clock for the purpose of ascertaining the longitude at sea; and in 1544 the corporation of master clock-makers at Paris obtained a statute from Francis I., whereby any one not an admitted master was forbidden to make clocks, watches, or alarums, *large* or *small*. In making clocks portable, the substitution of a main-spring for a weight, as the maintaining-power, must have been made; this, with the invention of the *fusee*, introduced a new era into the art of horology.

The next great discovery in the art was the *isochronism of the pendulum*, made by Galileo while pursuing his studies at Pisa about the year 1581.[1] In 1583 he recommended the pendulum to be used in measuring time. In his first applications of it to astronomical observations he employed persons to count and register the oscillations, but he soon saw the want of means for effecting this by machinery, and fifty years later he describes his "time-measurer," or pendulum clock, "the precision of which is so great, and such, that it will give the exact quantity of hours, minutes, seconds, and even thirds, if their frequency could be counted; and its constancy is such, that two, four, or six such instruments will go on together so equally, that one will not differ from another so much as the beat of a pulse, not only in an hour, but even in a day or a month." The honour of first applying the pendulum to a clock has been also claimed by Huyghens, who before the year 1658 certainly superintended the making of a pendulum clock, and whose excellent treatise "*De Horologio Oscillatorio*" led the way to many of the subsequent improvements in clock-work. He showed that the larger arcs of vibration of a pendulum occupy rather more time than the smaller, and that the time of a semicircular vibration is to that of a very small one, as 34 to 29. It should, however, be stated, that a countryman of our own is entitled to some share of the honour which has been contested by Galileo and Huyghens; for in 1641 Richard Harris made a long-pendulum clock for the church of St. Paul's, Covent-garden. It has however been suggested that Inigo Jones, the architect, having been in Italy during the time of Galileo, may have communicated to Harris what he had heard of the pendulum. Huyghens also constructed a marine-clock, and he discovered that its pendulum vibrated more slowly as its approached the equator, which led the way to the subsequent discovery of the oblate spheroidal form of the earth. He also discovered that the isochronism of the pendulum is true only when the ball moves in the involute of a cycloid; hence *cycloidal cheeks* were contrived for causing the ball to describe that curve; but as no substance could be found of sufficient strength and flexibility to form a thread which should easily wind on the cycloidal cheeks, and at the same time not to adhere to them, the cycloidal pendulum, although perfect in theory, was found to be inferior in practice to the common pendulum; besides, when vibrating in very small arcs of a circle, its vibrations are, for all practical purposes, isochronous, because the circle has the same curvature as the cycloid at its lowest point, and may be taken as identical with it for a small distance.'

In 1676, a London clockmaker named Barlow invented the *repeating* mechanism, by which the hour last struck may be known by pulling a string. Much ingenuity was also thrown away upon the construction of clocks for showing both mean and apparent time. The most important invention of this period was the *anchor escapement*, the invention of which has been referred by some to Dr. Hooke,[2] and by others to Clement, a London clockmaker. "The great advantage of this escapement over the old crown-wheel is, that it allows the escape to take place in a small arc of vibration, thereby preventing the necessity for the maintaining power acting upon the pendulum with so great a force as by the old plan, and by the introduction of a heavy ball, leaving that to be done by the uniform power of gravity, which before was dependent upon the impulse given by the wheel to the pallets. This change in the escapement introduced the practice of suspending the pendulum by a thin and flexible spring, another invention of Clement's; although this has also been claimed for Dr. Hooke. The seconds pendulum with this escapement was called the *royal pendulum*.

The next great invention in the art, was the introduction of the *compensation* for counteracting the effects upon the length of the pendulum of changes of temperature. In 1715, George Graham

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(1) It is stated that the Arabs, as early as A.D. 1000, were acquainted with this property of the pendulum, and used it as a [illegible] measure of time.

(2) [illegible] the pendulum [illegible] stated [illegible] Mechanics, published in Weale's Rudimentary Series.

Hooke [illegible] stated that the [illegible] invented by [illegible] the crown-wheel [illegible] pendulum [illegible] was made to swing in very [illegible] that he could not have [illegible] with the knowledge of the anchor escapement [illegible] were used to [illegible] the pendulum, and Huyghens himself [illegible] that the [illegible] of the parts which produced the cycloidal motion would cause a greater irregularity than a circular vibration of even 10° or 12° could do.

substituted a jar of mercury for the pendulum ball, and thus succeeded in retaining the point of suspension and the centre of oscillation at the same distance from each other. Graham also suggested the idea of making use of the opposite expansions of different metals as a compensation for a pendulum; an idea which was realized by Harrison, who also introduced it into the balance wheels of watches, and succeeded in constructing a timekeeper which determined the longitude within such limits as to procure for him, in 1767, after much previous trial and inquiry, the parliamentary reward of 20,000*l*. Harrison also invented the *going-fusee*, by which a watch can be wound up without interrupting its movement.

It would be quite impossible within our limits even to notice the variations and improvements in clocks and watches which have been made within the last 50 or 100 years. Escapements alone have formed a theme for constant variation; and this is so favourite a subject, that almost every person of a mechanical turn has either made or planned some novelty in this way. Indeed, a celebrated clockmaker is reported to have said, that for a wager he would undertake to invent a new escapement every morning before breakfast.[1] It is, however, important to notice in this place the distinction between the *recoil escapement* and the *dead-beat escapement*. In the anchor escapement, already noticed, the pendulum vibrates some distance after the tooth has performed its office of impelling the pallet forward; the effect of which is to give a recoil or retrograde movement to the wheel, which may be noticed in the seconds hand of any common house clock. In such a clock this effect is of no great consequence, and as this recoil escapement is easy to make, it will probably continue in use. But for astronomical and other good clocks the recoil is objectionable as a source of error; Graham therefore contrived the dead-beat escapement, in which, however far the pendulum may swing, no recoil can take place. The *duplex* and *remontoire* escapements will be noticed hereafter.

Wooden clocks have been in use for about 200 years. They were first produced in Holland, and hence called *Dutch* clocks; but the manufacture has for a long time been mostly confined to the Duchy of Baden. Ornamental drawing-room clocks are still largely manufactured in France.

Dismissing historical details, we will now endeavour to lay before the non-professional reader a brief statement of the principles of horology.

It is a principle of mechanics that in every uniform motion, the spaces described are proportional to the times occupied in describing them. Such a motion is well adapted to the measurement of time, since it refers this measurement to that of the spaces described by the moving body. Hence in the construction of time-measurers the first thing required is the means of producing a uniform motion. But, in order that a machine may always move with the same velocity, the force which moves it must always be in equilibrium with the resistance which it has to overcome. If the resistance continue constant, the power will constantly act with the same intensity: if the resistance vary, the power must vary at the same rate, in order that equilibrium may not be disturbed. In the motion of a machine the number of resistances of various kinds is so great, and liable to such constant variation from changes in temperature, in moisture &c., that it does appear at first view extremely difficult so to arrange the power that it may be constantly in equilibrium with the resistances. In clock and watch work, these difficulties are rather eluded than overcome, as we shall now endeavour to explain.

The power employed to impart motion to instruments for measuring time, may be either a *weight* or a *spring*. This, in either case, is called the *maintaining power*.

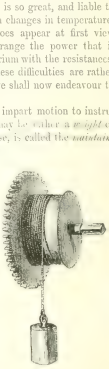
Fig. 1157

In order that a weight may act as a maintaining power, it is suspended from the extremity of a cord which is coiled round a short cylinder moving on a horizontal axis, the other extremity of the cord being attached to the cylinder. See Fig. 1157. As the weight tends constantly to descend, it communicates a rotatory motion to the cylinder, which motion can be transmitted to the mechanism of the clock by means of a toothed wheel attached to the cylinder.

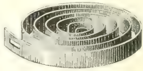
Fig. 1158.

The springs employed as moving powers in timepieces, are long thin ribbons of steel, coiled up into a spiral form as in Fig. 1158. The outer extremity of this spring (called the *main-spring*) is attached to a fixed point, while the inner extremity is fastened to an axis, which being turned round in the proper direction, carries round with it the interior extremity of the spring, whereby the spiral coils are brought closer together, and the spring assumes the form of Fig. 1159. Now as the spring tends con-

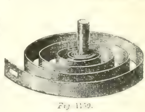
Fig. 1159.

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(1) See M. Adam Thomson's "Time and Time-keepers," p. 117. The English appear to have monopolised the inventions in this important branch of the art. The inventor of the vertical escapement is unknown; the horizontal or cylinder escapement is by Graham; the lever escapement by Mudge, the duplex by Dr. Hooke, and perfected by Tyrer. The detached escapement, although invented by Berthoud, owes its accuracy to the improvements made by Arnold and Earnshaw.

stantly to uncoil or to assume its original form, it will in doing so cause the axis to rotate, and this rotatory motion is communicated to the mechanism of the clock or watch by means of toothed wheels and *pinions*. It is evident that this arrangement may be so far altered that the inner extremity of the spring may be fixed, while the outer extremity, being attached to a piece of mechanism capable of revolving round the axis of the spring, it would equally communicate a rotatory motion to this piece.

If we compare the action of the spring with that of the weight, an important difference will be discovered. The weight acts always with the same intensity, while the force of the spring goes on constantly diminishing from the moment when it begins to uncoil until it has reassumed its primitive form, Fig. 1158. The uniformity of action in the moving power, so necessary to the proper going of a time-keeper, is secured by employing a descending weight as in a clock, but where there is no space for a weight, or where portability is required, and a spring must be used as the moving power, its action is made uniform by an ingenious contrivance called the *fusee*. The spring is enclosed within a short cylinder A, Fig 1160, named the *barrel*, to the surface of which is fixed the extremity of an articulated chain B, which,

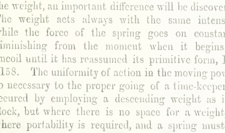

Fig. 1160.

after being coiled a certain number of times upon the barrel, is attached by its other extremity to the lower part of a conical piece C, called the *fusee*. This fusee is furnished with a helical groove for receiving the coils of the chain. When the spring is completely stretched, the chain exactly fills the grooves of the fusee, with the exception of the small piece which proceeds from the narrowest portion of the fusee to the barrel. The force of the spring in uncoiling causes the chain to uncoil from the fusee and to roll upon the surface of the barrel, and this action continues until the chain is completely detached from the fusee, except that small portion which stretches from the larger base of the fusee to the barrel. Now it is evident that during this motion the tension of the chain, depending as it does upon the force of the spring, goes on constantly diminishing; but as this tension acts upon the fusee at the extremity of a lever which gradually increases in length, the curve of the fusee has been so determined that there shall be an exact compensation; that is to say, the action of the chain produces the same effect as a constant force applied to the extremity of a lever of a constant length.

It will therefore be understood that the fusee is a variable lever, upon which the main-spring acts through the medium of the chain. "A common observer would say of the fusee that it was a sort of cone, upon which the chain was wound from the barrel, by the operation of winding up the machine; but it is in reality a mathematical curve, which has this peculiar property,—that as the chain winds upon it, the distance from the centre of motion of the fusee to the semi-diameter of the chain which is in contact with it, continually varies; and also that it varies in this proportion, viz. that the distance of the centre of motion of the fusee to the semi-diameter of the chain, at that point where it leaves the fusee for the barrel, multiplied by the force of the main-spring acting on the chain at that time, shall be what mathematicians term 'a constant quantity:' that is, shall be the same whatever point of the fusee may be taken. Thus: suppose the chain which receives its power to turn the fusee from the main-spring pulls with a force of 9 oz., and that the distance from the centre of motion of the fusee to the semi-diameter of the chain at that part where it leaves the fusee is 42 hundredths of an inch, or expressed decimally, ·42; then 9 × ·42 = 3·78. Now let the spring be wound up to different points, at which its force will be respectively 12 oz., 18 oz. 20 oz., 30 oz., and 40 oz., the corresponding distances at which the chain must pull from the centre of the fusee will be respectively ·315, ·210, ·189, ·126, and ·0945 of an inch, for ·315 × 12 = 3·78, ·21 × 18 = 3·78, ·189 × 20 = 3·78, ·126 × 30 = 3·78; and ·0945 × 40 = 3·78. Thus at any given distance from the centre of motion of the fusee, its power to turn any machinery is uniformly the same; and as the great or main wheel which communicates motion to all the rest in the watch or chronometer, is attached to the fusee, their centres of motion coinciding with each other, it follows that the power at the teeth of the main wheel is perfectly uniform."

The maintaining power, whether it be that of a descending weight or of a spring, is transmitted through a train of wheels and pinions. It first turns a central axis or arbor to which a spur-wheel is attached: the teeth of this wheel engage with, or lock into, the spaces between the teeth of a smaller wheel or pinion, which is fixed to a second axis parallel to the first: this second axis also carries a toothed wheel, which engages with a pinion fixed to a third axis, and so on. Now if the main-wheel, or that attached to the first axis, have six times more teeth than the pinion which engages with it, the second axis will evidently turn round six times quicker than the first; if the wheel of the second axis have four times more teeth than its corresponding pinion, the third arbor will turn round four times quicker than the second, and consequently twenty-four times quicker than the first. Thus it will be seen that the rotatory motion of the first axis is transformed into the rotatory motions of the second, of the third, of the fourth, &c., constantly increasing in velocity; and the relation between the velocities of two consecutive arbors will be that of the numbers of teeth in the wheel or pinion which transmits the motion from one to the other.

Having thus given a general idea of the arrangement of the train of wheels and pinions in a clock or watch, and of the power which sets them in motion, we have next to show how this movement is regulated so as to cause the hour, minute, and seconds hands, to move uniformly over the surface of a dial.

It has been stated that in order to render the motion uniform, a permanent equilibrium must be established between the power and the sum of the resistances. For this purpose there may be attached to the last arbor of the train, or that which has the greatest velocity, certain pallets, which strike the air during their motion. They are of the form shown at *f f'*, Fig. 1161, and consist of a thin plate of metal, on two opposite sides of the axis with which they revolve. The resistance which the air opposes to their motion varies in proportion to the square of their velocity, the consequence of which is that when the motion begins to be produced, the resistance experienced by this *fly*, as it is called, is very small: the moving power is too great to allow of equilibrium being at once established, and the velocity of the whole train goes on increasing. But this increased velocity increases the resistance to the motion of the pallets, and the mechanism soon attains such a velocity that the power is in equilibrium with the resistances; the motion then continues uniform, and remains so as long as the power preserves the same intensity.

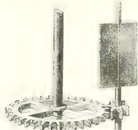
Fig. 1161.

There are, however, objections to this method of regulating the movement. The air which acts upon the fly is subject to considerable variations in density; moreover, the least change in the magnitude of the moving power, and in the friction of the different parts, disturbs the equilibrium, and, consequently, the *rate* of the whole mechanism. Hence the fly is not used where the precision of a clock is required. It is, however, used in the striking part of clocks, in musical snuff-boxes, in smoke-jacks, in Carcel lamps, &c., but in such cases the moving power is a spring which acts directly upon the train of wheels, so that although regular at any given moment, the rate goes on gradually diminishing until the spring has become quite relaxed, and all motion ceases.

As the means just indicated do not produce a motion sufficiently uniform for measuring time, a contrivance has been invented for producing not a continuous, but a periodically uniform motion. A piece of mechanism is made to oscillate in a regular manner, so that at each oscillation the whole train of wheels shall for a moment be stopped, thus producing an intermittent motion, and the hands which serve to indicate the time upon a dial-plate, instead of turning with one continuous motion, advance by a series of jerks; but each jerk passes over so minute a portion of space that the eye cannot distinguish it in the hour and minute hands, from an extremely slow continuous motion; in the seconds hand, however, this jerking motion is evident.

The piece which oscillates in the manner referred to, is called the *regulator*; the apparatus which connects the train of wheels with the regulator, and serves to arrest at each instant the motion of the wheel, is called the *escapement*.

The regulator employed in clocks and watches, consists of a metallic wheel, tolerably heavy at its circumference, moving upon an axis, to which it is attached at the centre. This wheel is called the *balance*; its oscillations upon its axis are of course produced by the maintaining power, the main-spring or the weight, transmitted through the train of wheels and the escapement. This will be evident from Fig. 1162, which exhibits at one view the several acting parts of a small portable time-piece, showing the connexion of the different parts. For the sake of clearness a few things have been omitted which will be explained separately, and the arbors or axes of the different wheels and pinions have been lengthened so as to remove the parts to a much greater distance from each other than is adopted in practice.[1]

A is the main-spring, the outer end of which is fixed to the base of the upright pillar; the uncoiling of this spring gives a rotatory motion to the axis *t*, to which it is attached at its inner extremity. This axis is furnished with a ratchet-wheel B, which acts upon the spur-wheel C, by means of the click *o*. The wheel C gives motion to a pinion D, and consequently to the wheel E, which in its turn moves the pinion F and the wheel G; the wheel G imparts motion to the pinion H, and the axis of this pinion causes the scape-wheel M to revolve by means of the crown-wheel K and the pinion L. The axis of the crown-

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(1) Fig. 1162 is copied from Berthoud's fine old Treatise, entitled "Essai sur l'Horlogerie," 2 vols. 4to. Paris, 1763. We are also indebted to this work for several other figures. We have also consulted the splendid work, by the same authority, entitled "Histoire de la Mesure du Temps par les Horloges," 2 vols. 4to. New Edition, Paris, 1802. Also his "Traité des Horloges Marines," 4to. Paris, 1773, and the Supplement, 1787.

The reader interested in this subject will also do well to consult Thiout's "Traité de l'Horlogerie, mechanique et pratique," 2 vols. 4to Paris, 1741. This treatise is illustrated with [illegible] large copper-plates, containing representations of the tools and engines used in making the tools in general use by the clockmaker, together with abundant illustrations of the different parts of clocks, repeaters, watches, &c. Although a great part of the machinery here figured may be considered as more curious than useful, yet it cannot be said to have been unproductive. The inventive faculty thus constantly stimulated and exercised in the production of toys, produced also useful machines, and laid the foundation for the modern school of engineering, which gave birth to such marvels as the Steam Engine, the Vertical Printing Press, and the self-acting Spinning-mule. When a man of genius is engaged, as George Graham was, in making a planetarium for the amusement of an Irish lord, Lord Orrery, whence these things are called *Orreries*, he is also enriching mechanical science with new motions and new combinations, which can afterwards be applied to far more important purposes.

wheel turns with one end in a branch *c* of the *potence* I, and the other in the counterpotence J. Opposite the scape-wheel M, the teeth of which are cut in a particular manner, is the axis, or *verge*, of the balance N; this axis is furnished with two pallets *i i'*, placed at right angles to each other, and so arranged with respect to the upper and lower parts of the wheel M, as to fall into the teeth thereof in such a way that as the wheel rotates its teeth alternately fit into one pallet while the other is escaping therefrom. The pallet *i* receives an impulse which causes it to move from the front to the back; but soon the other pallet *i'* is in the path of one of the teeth of the wheel M, and receives an impulse therefrom which brings it into the front; whereupon the pallet *i* is again placed in such a position as to engage with the teeth of the wheel and is pushed into the front, and so on. To prevent the balance being carried round too far, two pins 1, 2, are placed upon it, and as soon as the vibration amounts to 180° they strike against a fixed tongue K, and are prevented from going any further. This is called *banking* the balance.

In the case before us the escapement is formed by the scape-wheel M and the two pallets *i i'*; and it is called a *vertical recoil escapement*, because each time that one of the pallets strikes one of the teeth of the wheel, the balance, which has not yet lost all its motion, causes the wheel to start back or recoil a small space. By employing the balance and the recoil escapement, the movement is not regulated in a manner altogether satisfactory. Each oscillation of the balance is communicated by the action of one of the teeth of the scape-wheel upon one of the pallets, and this motion is performed with greater or less rapidity, according as the pressure of the teeth upon the pallet is more or less intense. In the case before us, the force of the main-spring is constantly varying, as is always the case where no fusee is employed; the friction of the different pieces upon each other is also liable to variation, especially from the thickening of the oils used to lubricate them; these and other causes prevent the pallets from receiving the same impulse at different times, so that the successive oscillations of the balance are not of the same duration.

Fig. 1162 will also enable us to understand how the train of wheel-work causes the motion of the hour and minute hands upon the dial-plate. The axis of the wheel E is prolonged, and at its extremity is attached the minute hand. It is necessary, therefore, that the main-spring and the regulator be so arranged that this axis shall perform a complete revolution in an hour. On this axis is mounted a pinion P, which engages with a wheel Q, and the axis of the wheel Q carries a pinion R, which engages with a wheel S. This last wheel is attached to a hollow cylinder *b*, through which passes, with slight friction, the axis which carries the minute hand, and it is at the extremity of this hollow cylinder that the hour hand is fixed. In this way the two hands may have a circular motion round the same centre, and yet be moved at very different rates. The pinion P has 8 teeth, and the wheel Q 24; the minute hand, therefore, makes 3 turns, while the wheel Q makes but 1. On the other hand, the pinion R has 8 teeth, and the wheel S 32, so that the wheel Q makes 4 turns while the wheel S makes but 1; the wheel S therefore makes 1 turn while the minute hand makes 12, and, consequently, the hollow cylinder, which serves as an axis to the wheel S, gives to the hour hand its proper rate of motion.

The wheels and pinions, P, Q, R, S, with the hour and minute hands, are set in motion by the axis of the wheel E. Motion is communicated from this axis to all that part of the mechanism situated immediately below the dial, in such a manner that the hands can be made to move without turning the wheel E. For this purpose, instead of a single axis carrying the wheel E, the pinions D and P, and the minute hand, two axes are employed, placed end to end, one of which carries the wheel E and the pinion D, and the other the pinion P and the minute hand. One of these two axes is hollow at its extremity, and the other axis passes into this hollow with some amount of friction, so that when one of the axes is made to turn, the other will turn also unless it experiences a resistance capable of overcoming the friction between the two. When the wheel E turns, it moves the pinion P, and the hands also, which present only a feeble resistance; but, on setting the watch to the correct time by turning the minute hand, the axis of this hand does not in such case set in motion the axis of the wheel E, on account of the resistance offered by the whole train with which it is connected. The minute hand being moved causes only the wheels and pinions P, Q, R, S, to move with it, while all the other wheels continue stationary.

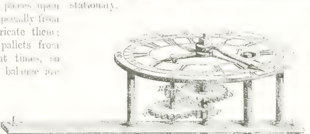

Fig. 1162. PRINCIPLE OF THE WATCH ILLUSTRATED.

During the going of the watch the spring gradually enlarges its coils, and becomes slack; it therefore requires to be wound up after certain intervals, for which purpose a key is adapted to the square extremity T of the axis, to which the interior end of the spring is attached, and this axis is turned in a direction contrary to that in which the spring acts upon the train. If the wheel C were fixed to this axis, it would turn with it during the winding up, and thus impart to the whole train and to the hands a retrograde motion. To prevent this inconvenience, the axis of the main-spring is made to act upon the wheel C only through the medium of the ratchet-wheel B and a click *o*, which is kept in its place by the pressure of a small spring *o'*. By this arrangement the wheel C is moved by the axis only when the latter yields to the impulse of the main-spring; and when this axis is turned in a contrary direction, as in winding up the watch, it carries with it only the ratchet-wheel B, the teeth of which passing in succession under the click *o*, produces the sound so well known to every one who has a watch. Hence, during the winding up, the train of wheels and the hands remain stationary.

If the above description of the mechanism of an ordinary watch is well understood by the reader, he will have but little difficulty in following out those variations which distinguish a clock from a watch. The importance of a pendulum in regulating the movement of a clock has been already referred to. The escapement commonly employed for transmitting an impulse from the train to the pendulum is shown in Fig. 1163. It is called the *anchor escapement*, and consists of a piece of metal shaped something like an anchor, suspended from a horizontal axis, on which it can freely turn. Fig. 1163 shows the common form of anchor pallets, in which a tooth *a* is represented as having just escaped from the pallet A, and a tooth *b* on the opposite side of the wheel has dropped on to the pallet B. The pendulum will not, however, stop here, but will advance a little further to the left; and thus the slope of the pallet B will drive the tooth *b* a little way back, and produce the *recoil*. No particular form is required for such pallets. "Their acting faces are generally made flat, but they are better convex, as there is then less recoil and less wearing of the pallets by the points of the teeth. Strange as it seems that brass teeth should wear holes in steel made as hard as it can be tempered, it will always be found that the teeth have worn holes in these pallets after a few years, and the hole will be deepest towards the end of the place which the tooth reaches. It is evident that the tendency to make this hole will be less if the pallet is convex, than if it be flat." The recoil escapement is converted into a dead escapement,[1] Figs. 1163, 1164, "by making the slope of each pallet stop at the points A and B where the teeth fall, and making the rest of the pallets A D and B E portions of a circle whose centre is C, the axis of the pallets. For, in that case, however far the pendulum may swing, no recoil can take place. The reason why this escapement is so much better than the recoil escapement is, that a variation in the force of the clock train produces hardly any effect upon the time of oscillation of the pendulum, though it produces a considerable effect upon the extent of its oscillation." Although we cannot determine the proportion which the increase of the arc bears to that of the force, since it depends upon the varying friction of the different parts of the clock, yet they have a tendency always to correct each other; and when even the state of the clock is such that the arc increases just one-third as much as the clock-weight is increased, these two parts of the error will exactly counteract each other; but it generally happens that as the clock gets dirty the force and the arc decrease in such a proportion that the loss of time preponderates. But there is one case in which the opposite effect takes place, to the surprise of those who know the common result of a decrease of arc. Church clocks will often be found in a few months after they are put up to increase their arc of vibration considerably, and at the same time to gain. Mr. Denison discovered this increase of arc to arise chiefly from the decrease of friction on the dead part of the pallets, owing to the teeth and pallets polishing themselves more perfectly than had been done by the maker.

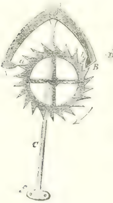

Fig. 1163

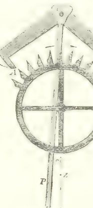

Fig. 1164

When a clock gains it is said to have a + daily rate of so many seconds, and when it loses, a — rate; but these signs are the reverse of those which indicate the decrease or increase of the time of an oscillation. The goodness of a clock is indicated, not by its rate, but by the variation in its rate.

The effect of the self-polishing of the pallets is only temporary; and the general effect of a decrease of force and space in a dead escapement is that the clock gains a little, whereas a common recoil escapement loses considerably as the arc decreases; and this has led to the adoption of a small recoil in the place of the dead part of the pallets. This recoil is given by striking the circle of the dead part of the pallets, not from the axis of the pallets, but from a point a little below that axis, in the line of centres of the pallets and the scape-wheel, which produces a circle of a higher degree of curvature, and, therefore, raises the teeth a little after they have dropped on to

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(1) These two figures and the description are copied from Mr. Denison's valuable treatise on Clock and Watch-making, published in Weale's Rudimentary Series, 1850.

the pallets; and the further the pendulum swings, the greater is the degree of recoil. This is commonly called the *half-dead escapement*.

Another form of dead escapement, much used in the construction of turret-clocks, is called the *pin-wheel escapement*; it consists of pins set on the face of the scape-wheel, instead of teeth on its edge; the two pallets, instead of embracing about one-third of the circumference of the wheel, are put so near together as to leave room for only one pin to pass between them; and the end of one slope is situated just over the beginning of the other. The pins are half-cylinders: as the upper part of the cylinder could not act, the cutting it away allows the pallets to slip through close above the teeth, so as to waste as little drop as possible.

An escapement invented by Professor Airy, and named the *duplex spring escapement*, is intended to prevent the irregularities of force of the train affecting the impulse on the pendulum. For this purpose there are two scape-wheels and two pairs of pallets, one for the stop and the other for the impulse: the stop-wheel is the one connected with the train, and the impulse-wheel rides on the same arbor, and is connected with the other by a spiral spring. The stop-wheel is let go by its pallets, which have no sloped faces, just before a tooth of the impulse-wheel would arrive at the slope of its pallets, and so the tooth is carried down the slope and the impulse given by the force of the spring only.

Escapements of this kind, in which the impulse is given to the pendulum by a small separate weight or spring, independently of the force of the train, are called *remontoir* escapements, because the clock train winds or lifts up the maintaining force at every beat, or at some given number of beats of the pendulum. Or to explain the matter a little more fully: In this form of escapement the impulses given to the pendulum are not imparted by the large going-train of the clock, which is exposed to variations of force and resistance from varying friction, from changes in the viscidity of the lubricating oil, from the effect of wind upon the large hands of the external dials which in the Royal Exchange clock are each 9 feet in diameter; but the impulses are imparted to the pendulum by a small secondary train, set in motion by the descent of a balance weight, which is itself raised at intervals of 20 seconds, by the mechanism of the going-train. In some cases a *remontoir spring* only is used for the purpose of setting the escapement in motion, it being itself wound up at very short intervals by the going-train, which receives its impulse from the prime mover. Now, as the velocity of the machine is determined by the escapement, so by detaching this from the power, whether a weight or a spring, which is always subject to some irregularity, a more accurate performance is ensured. [See WATCH, Cyc. and APPENDIX.]

Fig. 1165 shows the method of connecting the anchor with the pendulum. The horizontal axis D to which it is fixed has attached to it a stem F, which terminates at its lower extremity in a horizontal fork or crutch G. The rod of the pendulum passes between the limbs of this fork, closely but not so tightly as to prevent the rod sliding within it when required, so that the pendulum cannot vibrate without the anchor vibrating also. The crutch c and the fork *f* are also shown in Fig. 1163.

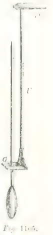

Fig. 1165.

In the recoil escapement, the weight is constantly acting on the regulator so as to modify its rate of going. In the dead beat, the influence of the weight is almost entirely removed, for it is exerted only in the friction of the teeth of the scape-wheel in the pallets, (which can be reduced to a very small quantity,) and in the impulses which the pallets receive from the teeth at the moment when they escape. If in addition to this we consider the isochronism of the pendulum, when vibrating in small arcs, some idea may be formed of the great accuracy to which clocks may be brought as measurers of time.[1]

The duration of each vibration of the pendulum, upon which the rate of a clock's going depends, is determined by the relation between the minute hand and the scape-wheel. The times of oscillation of different pendulums are as the square roots of the lengths of the pendulums. For example, if we take three pendulums whose lengths are as the numbers 1, 4, 9; then the times of vibration will be respectively as 1, 2, 3. That is, the pendulum whose length is 1, makes 2 vibrations to every 1 of that whose length is 4, and 3 vibrations to every 1 of that whose length is 9. For practical purposes this important law is expressed thus:—the times of vibration of different pendulums are in the same proportion as the square roots of the distances of their centres of oscillation from their axes of suspension. Now in order to regulate a clock so as to prevent it from going too fast or too slow, the bob of the pendulum admits of being screwed up or let down, so as to vary the distance between the centre of oscillation and the axis of suspension, or, in other words, to alter the effective length of the pendulum as required. When the clock gains, each vibration of the pendulum lasts too short a time: it is lengthened by letting down the bob through a small space. When the clock *loses*, the bob is raised, the effect of which is to shorten the effective length of the pendulum, and to cause it to beat more quickly.

Figs. 1166, 1167, show the arrangement of a clock which is regulated by a pendulum and an anchor escapement. The moving power or weight A, acts from the extremity of a cord, which is wound upon

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[1] In order to ascertain how much of the first power of the clock is wasted in the friction of the train and pallets, or how much a given escapement requires, remove the pallets and fix to the scape-wheel or its arbor an arm of any convenient length, and hang small weights to the end of it till the weight that the clock will just drive is found, the arm being horizontal. The arm should have a counterpoise and be as light as possible, so that its own weight may not enter into the question or add much to the friction of the scape-wheel pivots.

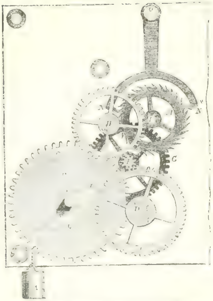

Fig. 1166.—[illegible]

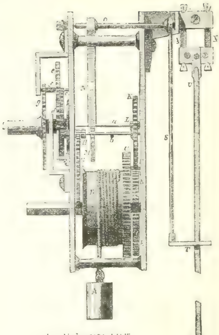

Fig. 1167.—Side View.

[illegible] wheel F, which it turns [illegible] it the wheel C. This wheel C engages with a pinion D, the axis of which carries a second wheel E. The pinion F engages with the wheel E, and upon the axis of F is fixed a third wheel G, which in its turn engages with the pinion H, upon the axis of which is the fourth wheel K; K engages with L, on the axis of which is the scape-wheel M. The anchor N N, moving on an axis O, encloses the upper part of the scape-wheel M. The axis O, Fig. 1167, carries a rod S, whose fork T embraces the pendulum rod U U, of which V is the bob. The pendulum is suspended by two pieces of steel spring X X, which bend in one or other direction, according to the vibration of the pendulum. "It is of great importance," says Mr. Denison, "that the real point of suspension of the pendulum, that is, the top of the spring where it begins to bend, should be kept firmly in the same place; for if it moves it will increase the time of vibration, since this is evidently the same thing as if the fixed or real point of suspension was a little higher up, or the pendulum so much longer. For this reason, in the best clocks, the *cock* which carries the pendulum is a strong piece of brass, or in large clocks a cast-iron frame, fixed firmly to the wall at the back of the clock. In order that the pendulum may hang so that the spring will have no tendency to twist it as it swings, the top of the spring is pinched or *clipped* between two thick pieces of brass or iron called *chops*, and firmly screwed there; and these chops have square ends exactly at right angles to a line down the middle of the spring. A little way below the top of the chops and exactly in the middle, a strong steel pin is put through them and the spring between them, at right angles to the plane of the spring, and this pin has shoulders so that its thin ends beyond the shoulders will just drop into two nicks or V's, in the sides of the cock, with the shoulders resting against the sides. It is evident that the effect of this will be, that the weight of the pendulum will cause the square ends of the chops, and therefore the top of the spring, to be horizontal; and so, if the pendulum is made symmetrically, as of course it ought to be, it will vibrate in a vertical plane at right angles to the line which is the top of the spring, without any tendency to twist. The two V's should be made as nearly level as possible, and the clock-frame must be so placed that the pallet arbor is exactly at right angles to the plane of motion of the pendulum. If it is not, the pendulum will slide backwards and forwards in the fork by which it is connected with the pallets. In common clocks, both house and turret clocks, the cock is fixed to the clock frame, and has merely a slit in it into which the spring fits, having a piece of brass riveted on to the top to keep it from dropping through the slit."

The length of a pendulum beating seconds is 39·1393 inches.[1] Now, supposing our clock to be furnished with such a pendulum the seconds hand would evidently be fixed on the axis *a*, of the scape-wheel, Fig. 1167. The scape-wheel has 30 teeth, and as two vibrations of the pendulum are required in order that one tooth may occupy the place of its predecessor, it follows that the seconds hand will make a complete revolution in 60 seconds, or one minute. The pinion H, fixed to the axis *b* of the wheel K, is prolonged to the left of the figure, where it engages with a wheel *c*, fixed to a hollow cylinder which surrounds the axis of the seconds hand, and carries the minutes hand. By the side of the wheel *c*, and in the same hollow axis, is a second wheel *d*, which engages with a wheel *e*; the axis of *e* carries a pinion *f*, which engages with the wheel *g*; this wheel *g* is fixed to a second hollow axis, which surrounds the preceding and carries the hour hand.

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[1] A [illegible] the latitude of London would [illegible] own [illegible] steel and unopposed, [illegible] in a mean solar day, or 86 163 09 in a [illegible] day.

When the weight A has unwound the cord from the barrel B, the rotation of the barrel of course ceases until the weight has been again raised by winding the cord again on the barrel. This is done by turning the barrel in the contrary direction to its usual motion by means of a key, into which the square arbor *h* fits. To prevent the whole train of wheels and pinions partaking of this retrograde motion, a ratchet-wheel similar to that noticed in Fig. 1162, is employed here also. This ratchet-wheel r, Fig. 1166, is fixed to the axis of the barrel B, and consequently turns with it in whatever direction it may move. A click, Q, is kept pressing against the ratchet by means of a spring R. The click and the spring are attached to the great wheel c, so that when the barrel B rotates under the action of the weight A, the great wheel c must turn also by the pressure of the ratchet-wheel and the click; but when the barrel is turned in the contrary direction, as in winding up, the teeth of the ratchet-wheel pass rapidly in succession under the click, and the great wheel c does not rotate

The advantages of a pendulum as a regulator are evidently confined to clocks permanently fixed in a position where the pendulum can swing and the escapement act undisturbed. In watches and chronometers intended to be carried about, such a regulator has been contrived as shall be uninjured by alteration in position, and at the same time present as far as possible the advantages of the pendulum. The balance described in Fig. 1162 satisfies the first condition, but not the second. Such a regulator, deriving all its motion from the coiled spring, yields to all the variations in this force, and is subject to other changes as already noticed. But the objections to such a balance are got rid of by the introduction of the *spiral spring*, (another of Hooke's admirable inventions,) which enables it to oscillate almost independently of the main spring. It is of the same form as the main spring, Fig. 1158, but is minute in size and delicate in structure. Its interior extremity is attached to the axis of the balance and its outer extremity is pinned into a cock set on the frame of the watch. See Fig. 1175. The spiral naturally seeks the position of equilibrium; for whether the balance be turned in one direction or the other, the spiral coils are either extended or compressed, and tend by virtue of their elasticity to occupy the position of repose, or that given to them in the process of hardening and tempering, and thus restore the balance to its first position. But the moment the spiral has reassumed its position of equilibrium, the balance, moving by its acquired velocity, still continues to turn, causing the spiral to move also until the elasticity of its coils and the momentum of the moving wheel counterbalance each other, and the balance is for a moment brought to rest: the action of the spiral being thus at an end, reaction takes place, the coils move in a contrary direction, swinging round the balance, the momentum of which serves to distort the spiral spring until it again stops, and swings the balance back. In this way the balance is made to oscillate from one side to the other, resembling to a certain extent the vibrations of a pendulum. In effect the spiral is to the balance what the moving weight is to the pendulum. It is also important to note that the times of oscillation of the balance are independent of their amplitude, provided the spiral be properly arranged.

This valuable property of the balance does not, however, qualify it to act as a regulator without further aid. The escapement must be formed in such a way as to remove the balance as much as possible from the action of the main-spring, which would cause the time of vibration of the balance to vary according as the main-spring acted with greater or less vigour. For a long time the recoil escapement, or one with pallets such as is shown in Fig. 1162, was used, and is still used in common watches. In this case the part of the mechanism which serves to regulate the movement is arranged as shown in that figure, only that the axis of the balance is furnished with a spiral spring. The regularity of the motion thus obtained is very great, but much was still wanting. The balance was increased in value by the addition of the spiral; the escapement also required modification. We will notice the principal forms of escapement; the effect of which has been to make watches perform their work with very great accuracy.

The first is the *cylinder* or *horizontal escapement*; another invention of Graham's. The verge, instead of being provided with two pallets as in the recoil escapement, is of the form shown at B C, in Fig. 1168, and shown separately in Fig. 1169. The portion *a b* is a hollow half cylinder, which is further reduced by cutting out the portion *c*. The semi-cylindrical portion situated above *c* has an important office to perform. The scape-wheel is situated in a plane perpendicular to the axis of the balance, and its teeth elevated above its surface engage with the hollow cylinder as shown in Fig. 1168. Figs. 1170 and 1171 further illustrate

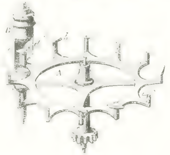

Fig. 1168.

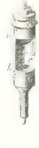

Fig. 1169.

the mode in which the cylinder arrests and allows to pass the teeth of the wheel. By means of the oscillations of the balance, the cylinder A rotates first in one direction and then in the other. A tooth C presents its point to the exterior surface of the cylinder, Fig. 1170, but immediately after this has taken place, the cylinder turns into the position Fig. 1171, and the tooth C, obeying the action of the motive force, is now brought into contact with the interior face of the cylinder; the cylinder then assuming its first position allows the tooth C to escape, and arrests the progress of the next tooth by presenting its exterior surface thereto, and so on.

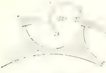

Fig. 1170.

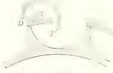

Fig. 1171.

In this escapement so long as one tooth is arrested by one of the two faces of the cylinder, the tooth does not tend in any way to make it move in one direction or the other, the cylinder oscillating under the action of the spiral only. Nevertheless, the friction which it undergoes in arresting the motion of the teeth, in addition to the other resistances which oppose the motion of the balance, tends to diminish the amplitude of its oscillations, and the watch would soon cease to go, if the main-spring did not from time to time restore to the balance the motion which these resistances tend to destroy. On this account the teeth are formed in such a manner that at the moment when the tooth C, Fig. 1170, having glided over the exterior face of the cylinder begins to escape, its convex form presses on the edge D, and thus accelerates the motion of the balance. For a similar reason the other edge, E, of the cylinder is bevelled so that when the extremity of the tooth attains this edge it glides over the small oblique face and gives an impulse to the balance.

The cylindrical escapement bears the same relation to the balance as the anchor escapement does to the pendulum. In these two escapements as soon as the tooth is stopped, either by the cylinder or by the anchor, it remains completely motionless or *dead*. In each escapement the regulator is constantly under the influence of the moving force, which although feebly exerted still exists, since the teeth rub upon the piece which arrests them, and at the moment when they are set at liberty they give an impulse to this piece. In order to get rid of the continual influence of the main-spring upon the regulator, the *chronometer escapement*, or *detached escapement* has been devised. It is called *detached*, because the vibrations performed by the balance are nearly detached from the pressure of the motive power during the greater part of its arc of vibration. This escapement is shown in Fig. 1172, in which *e* is the scape-wheel, made either of brass or steel, with the teeth considerably undercut: *p* is the steel roller or main-pallet, fixed on the arbor of the balance: it has an opening in it, the face of which is much undercut, and a piece of hard stone, such as a ruby, is set in this opening for the points of the teeth to act upon: *d* is a stud, firmly fixed to one of the plates of the chronometer; and to this stud the detent spring is secured by a screw: this spring is made very slender in the part *o*, and it is only by the yielding of this thin part of the detent-spring that any motion can be given to the detent for the purpose of unlocking the wheel, so that some part of this spring may be considered as the centre of motion of the detent; at *o* is a ruby pin, inserted in the detent in such a way that the teeth of the wheel may in succession rest on the pin, in which state the wheel is said to be locked: by means of a screw the distance of the ruby pin from the centre of the wheel, and consequently the strength of the locking, can be adjusted: to the inner side of the detent is attached a very delicate spring, called the *lifting-spring*, which rests upon, and extends a little beyond, the end of the detent. Concentric with the main-pallet, and just above it, is a small lifting-pallet, *p*. The mode of action is as follows:—In the position given in the figure, the lifting-pallet is about to move round with its face in contact with the lifting-spring, which in the course of vibration it lifts, and with it the detent, so as to raise the pin *o* clear of one of the teeth of the scape-wheel. By the time the wheel is free from the ruby pin, the main-pallet has advanced so far as to be ready to receive an impulse from another tooth, and before the tooth escapes the lifting-pallet parts with the spring, and the detent resumes its place on the head of the screw, in which position the ruby pin receives the point of another tooth, as soon as the tooth has escaped from the ruby face of the main-pallet. The balance having performed this vibration by the impulse given to the main-pallet, returns by the force of the balance-spring, and with it the lifting-pallet, the rounded side of which, pressing against the lifting-spring, raises it from the detent, and passes without disturbing the detent, which, is not again lifted till the balance has completed the present vibration, and returning for the next again brings the face of the lifting pallet in contact with the lifting-spring, which, with the detent, it raises, and the act of escaping again takes place, the balance making 2 vibrations for every impulse, as in the duplex, which is next to be described. Thus it will be seen, that at the moment when one tooth escapes, another tooth of the same scape-wheel gives an impulse to the edge of the indentation made in the main pallet, attached to the axis of the balance: and in this way the moving power by an almost instantaneous motion

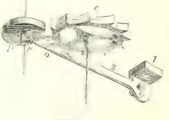

Fig. 1172.

restores to the balance the motion which it may have lost during two oscillations. With this exception it oscillates independently of the main spring. Another great advantage of this escapement is, that it requires no oil.

The *duplex* watch is so named from its escapement-wheel having two sets of teeth on its rim; the cogs *t′* being placed upright nearer the centre, while the long teeth *t* are in the plane of the wheel. Hence arises a *double* action. *b* is the balance. A watch of this kind will continue for a long time without cleaning, or requiring a fresh application of oil. It is, however, of delicate construction, and if not well made and put together, it is liable to stop in the pocket, and is expensive to repair if injured.

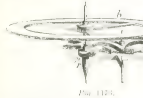

Fig. 1173.

The *lever* watch is one of the best forms for ordinary use. It is so named from there being a lever added to the action of the escape-wheel to give impulse to the balance. In Fig. 1174, *e* is the escape-wheel, which gives motion to the ruby pallets *p*: *l* is the lever which gives impulse to the balance *b*. This form is strong, not liable to get out of order, and is easily repaired.

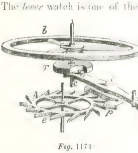

Fig. 1174

In pendulum clocks the rate of going depends upon the effective length of the pendulum: by screwing up the bob the clock goes faster; by letting it down it goes slower. The regulator of a watch requires adjustment in a somewhat similar manner. The duration of the oscillations of a pendulum depends upon the intensity of the earth's attraction and upon the form of the pendulum itself. As the earth's attraction is, at the same spot, a constant quantity beyond our control to alter, any variations in the oscillations of the pendulum must be made by altering its form. So also the duration of the oscillations of a balance depends upon its form and upon the force of the spiral which sets it in motion; but, contrary to what happens in the case of the pendulum, it is in modifying the force of the spiral, and not in changing the form of the balance, that the duration is varied. Thus by altering the fixed point of the spiral spring, the acting part is made longer or shorter. Thus in Fig. 1175, A B D is the spiral spring, or a portion thereof. Its outer end is pinned into a cock set on the frame at A. The pointer C B E turns on an annular or hollow pivot at C, the hole being left in its centre for the arbor of the balance, or the *verge* to go through. At B there are two small pins close together, between which the spring is passed, and which therefore determine the point from which it begins to bend; so that as the pointer or regulator, C B E, is moved towards the right, it makes the spring vibrate faster, and to the left, slower. When the regulator has been moved to the right as far as it will go, and the watch is still found to go too slow, the spring must be taken out and shortened by putting the outer end further through A, and drawing the inner end further out through the other cock by which it is pinned to the balance.

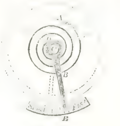

Fig. 1175.

Variations in temperature greatly influence the rate of going of a clock or watch, by causing the pendulum or the balance to contract or expand. The effect of a difference of temperature of 20°, or that which usually occurs between winter and summer, would occasion a clock furnished with a pendulum having an iron rod, to gain or lose six seconds in twenty-four hours. Different methods of *compensation* have been contrived to correct this source of error, or, in other words, to construct such a pendulum, that its centre of oscillation shall, under every change of temperature, remain at the same distance from the point of suspension. In the mercurial pendulum already noticed, the bob or weight consists of a jar of mercury so adjusted, that in proportion as the pendulum rod becomes longer, the mercury ascends in the jar, and *vice versâ*, by which means the centre of oscillation is always kept at the same distance from the point of suspension. In the gridiron pendulum parallel brass and steel rods are used, and the compensation is produced by the greater expansion of the brass rods, which raise the bob upwards towards the point of suspension as much as the steel rods elongate it downwards.[1]

In the chronometer the compensation is effected by means of an *expansion balance*, two forms of which, one with weights, and the other with screws, are shown in Figs. 1176, 1177. The making and finishing of a balance of this kind is one of the most difficult tasks which the mechanic has to perform. It is thus described. A circular piece of steel, of the thickness of the intended balance, is turned perfectly true, with a small hole in the centre, in which its arbor or axis is afterwards secured, and upon which it is ultimately poised. The piece of steel is then put into a melting-pot, and sometimes secured to it by a pin through a hole in the centre, with a quantity of fine brass, sufficient, when melted, to cover the steel. After a gradual cooling, the superfluous brass is filed away from each side of the flat piece of steel, so that the steel is completely cleared of brass everywhere except on the edge. If the juncture of the ring of brass to the steel which it now encircles be perfect, the brass is filed upon its outer edge so as to form a ring of tolerably equal thickness all round, but double the thickness required. It is next carefully and equally condensed with the hammer or burnisher; the steel is then turned out of the centre, and the brass from the outer edge, leaving a compound ring perfectly true, of the proper thickness for the balance, the brass portion being about twice the thickness of the steel. Within the steel rim, a bottom is left, out of which the bar A B is cut. When the balance is ready for adjustment, the compound rim is cut through on opposite sides, *a a*, so that each arm may present nearly a semicircle, secured at one end of the bar A B, and free to move through the rest of its length. The weights W W, Fig. 1176, are turned out of a piece of brass, with a groove equal in depth to the thickness of the balance, and of sufficient breadth to allow the brass to move round on the balance with a slight pressure. Each weight is secured in its place by a small screw passing through the outer edge, and pressing against the rim of the balance. Two screws, C C, called *mean-time screws*, are used for altering the rate of the time-keeper, and have nothing to do with the compensation.

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[1] In Captain Kater's Chapter on the Pendulum, appended to the Treatise on Mechanics in "Lardner's Cyclopædia," such instructions are given as will enable an artist or amateur to make a compensation pendulum.

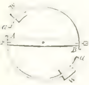

Fig. 1176.

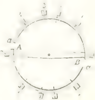

Fig. 1177.

This spring acts in the following manner: an increase of temperature diminishes the elastic force of the balance spring, which would cause the machine to lose; but the same degree of heat expands the outer brass ring on the rim of the balance more than it does the inner or steel one, and these not being able to separate, a curvature of the whole arm takes place, which carries the weight W towards the centre, whereby the inertia of the balance is so much lessened as to allow the balance-spring to exert the same influence over the balance as it had previous to the change of temperature. A diminution of temperature increases the elasticity of the spring, which would cause the machine to gain, but the brass contracting more than the steel, curves the arm outwards, thereby increasing the inertia of the balance, and allowing the spring no more influence over it than it had previous to the change of temperature. The proper situations of the weights W W are found by experiments on the rate of the machine. The nearer the weights are to the movable ends *a a* of the arms, the greater the space through which they move by any change of temperature, and the greater the variation in the inertia of the balance; so that if an increase of temperature cause the machine to lose, or a decrease to gain, it shows that the compensation is not sufficiently active; *i.e.* the inertia of the balance is not altered sufficiently to compensate for the effect produced by the increased or diminished elasticity of the spring, and consequently the weights must be set nearer to the moveable ends *a a* of the arms. If an increased temperature cause the machine to gain, or a decrease to lose, the weights must be moved further from the moveable ends *a a* of the arms. In adjusting these balances made with screws, it will be seen that the moving in or out of the screws 4 4, will produce a greater effect than 3 3, and these than 2 2, and so on, and that in the adjustment two opposite screws must always be moved in or out the same quantity. The mean-time screws C C produce no effect on the compensation, as no motion is given to them by the curvature of the arms. In every balance-spring of sufficient length, there is a part which is isochronal, or nearly so, and this length being found, it is not desirable to alter it in bringing the machine to time; for if shortened, the long vibrations will be quicker than the short ones, and if lengthened, the short vibrations will be quicker than the long ones. To avoid this source of error, the two screws C C have been introduced, the drawing out of which from the centre causes the machine to lose, and the screwing them in to gain.

Some years ago, Mr. Dent introduced a balance-spring of glass. Fig. 1178 shows one of his compensation balances, with the spiral spring attached.

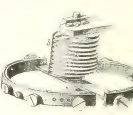

Fig. 1178.

The reader will now understand the essential differences between a clock and a watch. A clock or a watch has been defined as a machine consisting of a train of wheels turned by a weight, a spring, or any other nearly constant force, and of which the velocity is regulated by attaching to it a pendulum, balance, or fly-wheel, which always vibrates or revolves nearly in the same time. And the only distinction (except the arbitrary one of mere size) between a clock and a watch is, that a watch will go in any position, but a clock only in one. A chronometer is a very accurate kind of watch. What is called a *pocket chronometer* resembles a common watch, and is made to go the same time with once winding up, namely, 30 hours. Those used for determining the longitude at sea are larger, having dial-plates 3 to 4 inches in diameter, and are usually made to go from 2 to 8 days with one winding up. In addition to the hour, minute and seconds circles, there is one which denotes the time in days that has elapsed since the last winding up. Each chronometer is well secured in a brass box, mounted on gimbals, in order that one uniform position may be preserved, and the whole is enclosed in a mahogany case.

Where there is vertical space at command, a weight is used as the motive power, and a pendulum as the regulator. If the clock is to occupy only a small space.

as in chimney dials, a weight would be very inconvenient on account of the frequency with which it must be wound up. In such case a spring is substituted for the weight, but no fusee is used, since the regulator is a pendulum, the oscillations of which are not greatly influenced by the variations in the force of the spring. A main-spring and a balance, furnished with a spiral, are always used in watches, which differ from each other only in the form of escapement. In old watches the pallet or recoil escapement was used, as shown in Fig. 1162. Such an escapement required the intervention of a fusee to render uniform the action of the main-spring, notwithstanding its variations in force. In modern watches the use of the cylindrical escapement allows the fusee to be dispensed with, and a more thinner and flatter watch is the result. In chronometers the detached escapement is used, and the fusee retained.

When a clock is wound up, the hands do not make a retrograde motion, for the reason already explained, but remain stationary, and begin to move again when the winding is completed. In the exact observations of astronomy it is of importance to prevent the error likely to arise from the stopping of the clock during the operation of winding up. By the following contrivance by Huyghens, the clock can be wound up without stopping it.—The pulley A, Fig. 1179, furnished with a notched groove, is fixed upon the arbor of the first wheel. H is a similar pulley, pinned on the side of the ratchet R, and movable on a stud fixed in the frame. An endless cord is put over these two pulleys, and under the pulleys B and C, which carry the weights W *w*. It is evident that half of the large weight W is sustained by the pulley H, and the other half by the pulley A; and that half the weight will continue to bear upon A although the pulley H be turned so as to raise the weight W. This is what happens at the time of winding; for, by pulling the cord next *a*, the pulley H revolves, and raises or winds up the weight W, which still continues to act with half its weight on A, and consequently keeps the clock going. The ratchet R only turns during the winding, and is prevented by a click from going back. It is said, however, that this ingenious method does not answer very well in practice, unless a chain be used instead of a cord; for the pulleys A and H wear the cord so fast as to make a good deal of dust, which soon renders the clock foul. The chain is also objectionable on account of its weight, which sometimes aids and at other times counteracts the moving power.

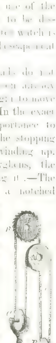

Fig. 1179.

When the maintaining-power of a clock or of a watch is a spring acting directly upon the train without the intervention of a fusee, as in Fig. 1162, the watch stops during the winding up, as already explained; but by a simple arrangement the maintaining-power can be kept up during the winding. For this purpose the main-spring is placed in a barrel attached to the great wheel, and it is wound up by turning round the axis to which its inner extremity is attached. It is evident that if this interior axis be left undisturbed, or it be made to turn so as to coil the spring round it, the outer extremity of the spring will constantly act upon the circumference of the barrel, and will cause the spur-wheel attached to it to continue its motion. It is in this way that the main-spring of chimney clocks is arranged, and also in flat watches, where the cylinder escapement allows the fusee to be dispensed with. Of course, the axis to which the spring is attached in the interior must be provided with a ratchet wheel, which allows the winding to take place in one direction only.

When the main-spring acts through the medium of a fusee, the winding up is performed by turning the fusee in a direction contrary to that in which it is accustomed to turn under the action of the main-spring. In this way the chain, which by the action of the spring had been dragged from the fusee and wound upon the barrel, is again wound upon the fusee: at the same time the barrel turns under the tension of the chain, and exerting a pulling force upon the exterior end of the main-spring, increases the number of the coils round its axis, and presses them closer together. In order that the retrograde movement thus given to the fusee during the winding up may not be transmitted to the whole train, a ratchet-wheel is provided, through the medium of which the fusee acts upon the train. The ratchet wheel is let into a cavity of the great wheel, which is furnished with a catch, by which the motion of the fusee is transmitted.

To prevent the stopping during the winding up, Harrison's *going barrel* or *ratchet* is used in weight clocks, and the *going fusee* in watches and spring-clocks. Fig. 1180 shows the barrel with its ratchet and click; but in this case the click, *c*, is not placed on the great wheel, but upon another wheel riding on the arbor of the barrel, between the great wheel and the barrel ratchet: this wheel has also ratchet teeth cut upon it, but turned the opposite way to the barrel ratchet, as shown at R; and the click, R C, belonging to it, is a long arm turning on a pivot C in the clock-frame; and this second ratchet-wheel is connected with the great wheel by a spring, S S, one end of which is fixed on the ratchet-wheel, and the other end presses against a pin on the great wheel. The action is as follows: while the clock is going, the weight pulls the barrel and both ratchets to the left, and the going ratchet, by means of the spring, S S, presses the great wheel in the same direction, and as the clock goes on,

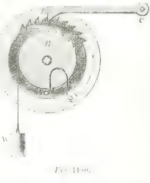

Fig. 1180.

one tooth after another of the ratchet R slips under the long click, and this causes the drop, which may be heard about every 5 minutes in regulators and good watches. When the weight is taken off the barrel by winding up, the going-ratchet immediately flies back a little towards the right, but is stopped as soon as one of the teeth arrives at the click, and there it is held: the spring continues to press the great wheel as before, with nearly as much force as when the weight is acting, and so keeps the wheel in motion for the short time that the clock is winding up.

That part of the clock which publishes the hours to the ear [illegible] complex as that which indicates the course of time to the eye. If, however, the clock is required to strike only once at every hour, all that is necessary is to attach a pin to either of the wheels of the dial-work that turns once an hour, and a hammer-tail or lever over it, so that the pin will begin to raise the hammer about a quarter before the hour, and just slip from under it when the minute-hand points to the hour. Instead of the pin, a flat piece of metal, cut into a spiral form, and called a *snail*, may be put upon the front of the wheel. The effect of this is to distribute the work of raising the lever over the whole hour with much less friction than in the former case. Now, it will be evident, that as the wheel H, Fig. 1181, bearing the minute-hand M H, goes round in the direction of the arrow once an hour, it will carry round with it, in the same time, but in a contrary direction, a similar wheel H′ with the same number of teeth engaging into it. Now the snail *s* being attached to this second wheel, and the hammer-tail H T resting on the snail, as shown in the figure, a few minutes after a stroke has been made, the snail, by gradually raising the hammer-tail, will remove the knob c of the hammer from the bell B until another hour is just on the point of completion, when the knob is at its greatest distance from the bell. During this time the spiral spring *a* is being more and more strained, so that when the snail suddenly releases the hammer-tail, the spiral spring causes the knob to strike suddenly against the bell, and the spring *b* forces it away again, and the point of the hammer-tail, falling into a position nearest to the centre of motion of the snail, as shown in the figure, the process goes on as before.

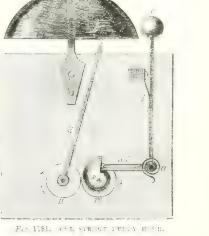

Fig. 1181.—ONE STROKE EVERY HOUR.

The arrangements for striking the hours and quarters is complex, and is often referred to technically as the *clock-work*, or the *clock-part*, the going part which moves the hands being called the *watch-work* or the *watch-part* even in a clock. Fig. 1182 shows the striking part of a clock in which the maintaining-power is a weight. The striking part is also moved by a weight attached to the cord R, which is coiled on the cylinder B, and the motion thus imparted to B is transmitted to the spur-wheel C attached to the same arbor. The wheel C engages the pinion D, and thus gives motion to a second wheel, E, which, acting on the pinion F, turns a third wheel, G: this transmits its motion to the pinion H, and consequently to a fourth wheel, I: I engages with the pinion K, and thus moves a fifth wheel, L: lastly, L turns the pinion M, the axis of which carries a fly, *f f′*, which regulates the movement. While this train of wheels is in motion under the action of the maintaining weight, certain pins, *a a*, projecting from one of the sides of the wheel G, successively raise the lever *b*, which lever causes the rotation of the axis *c*, to which the tail of the hammer is attached. As soon as one of the pins *a a* escapes from under the lever *b* after having raised it, this lever is forced by the action of a spring into

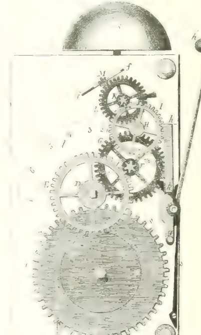

Fig. 1182.—THE STRIKING PART.

its first position, and the hammer *k* is thus brought towards the bell. If the tail of the hammer were rigid, the hammer would not strike the bell, but being flexible and elastic, the hammer, by its acquired velocity, passes beyond its position of equilibrium and strikes upon the bell, when it is immediately driven away again by the elasticity of its tail. Thus it is evident that the hammer must strike a blow upon the bell every time that one of the pins *a a* raises the lever *b*.

When the clock is not striking, a pin *o*, in the side of the wheel I, bears upon the extremity *h* of a lever *g h*, and the train of wheels is thus prevented from moving. This lever, moving on a point *g*, is moved aside by a pin fixed in the wheel on the arbor of the minute hand, (corresponding to E, Fig. 1162,) so that on the completion of each hour, when the clock is to strike, the pin *o* is thus released, and the train allowed to act. If the lever *g h* falls back into its first position, the wheel I is stopped after having made a single revolution: one only of the pins *a* acts upon the lever *b*, and the hammer strikes only once on the bell. In order that the hammer may strike the hour as indicated by the hands on the dial, a knife-edge, *k*, attached to the lever *g h*, presses upon the edge of what is called a *count-wheel*, shown by the dotted line *l*. Certain notches or indentations are made at unequal distances in the edge of *l*, which is called the *locking*-plate, and as it is attached to the axis of the great wheel E, it revolves in the same time with the striking movement, but with great slowness, and presents, in succession, the different parts of its edge to the knife-edge *k*. If, at the moment when the lever *g h* falls again, the knife-edge *k* enters into a notch, the extremity *h* of the lever stops the pin *i;* but if the knife-edge *k* is opposed to a portion of the wheel *l* situated between the notches, the lever *g h* cannot stop the pin *i*, and the striking apparatus continues to move until the wheel *l*, in turning, brings round a notch for the edge *k* to fall into.

The wheel *l*, which moves through only a small space each time the clock strikes, performs an entire revolution in 12 hours, at the end of which time the hours of the same name recur. During this time the wheel I revolves as many times as the hammer strikes the bell; *i. e.* 78 times if the clock strikes only the hours, and 90 times if the hammer strike once for each half-hour, as is common in French chimney-clocks.

The principle upon which the count-wheel is constructed does not allow of the hands being set back, and being liable to derangement, and troublesome to adjust, it has been superseded in English clocks by the *rack and snail*, (invented by Tompion, the father of English clock-making,)[1] which allow the hands to be set backwards or forwards as required. The count-wheel is still used in the best French clocks and in cheap wooden clocks.

Fig. 1183[2] will enable us to explain the *striking* and *repeating* work of an eight-days clock. In a companion figure, which we have not copied, are shown certain wheels, P Q R, with their respective pinions, which constitute the movement of the striking part, and the fan S regulates the velocity with which they move. The wheel P has 8 pins, which lift the cross-piece *t* of the arbor T 8 times in each revolution of the wheel P: these elevations of the piece *t* occasion so many revolutions of the arbor T, which arbor has its pivot projecting to V behind the frame, and carrying on its squared projection the hammer V. The hammer is consequently raised every time a pin of wheel P moves the piece *t;* W is a long and strong spring, called the *hammer-tail-spring*, attached to the back plate of the frame, and pressing with its upper extremity under the cross pin, passing through a hole in the arbor T, near the face of the back plate; so that when the hammer is raised at any time, the spring W urges it back again with a *smart blow*, and makes it strike the bell behind the frame; but to prevent the blow being too strong, a counter spring, U, is fixed to the contiguous pillar, which breaks the violence of the blow, and makes the hammer return smartly to its place when the blow is made; this spring U also serves as a guard, in case a stroke of the hammer should be made when the bell is taken off.

In the centre of the figure is the arbor of the centre wheel, the end of which is seen within, at the projecting end of the squared part of the tube, or cannon, and is called the *cannon-pinion:* the tube of this portion is put tight on the arbor of the hour or centre-wheel, and has a spring placed on the hour-wheel arbor, pressing its posterior surface so as to force it forwards against the cross pin that keeps the hands on: this action of the spring occasions so much friction, that although the tube is carried round by the hour-arbor, yet it is capable of being moved round by its hand placed on the square end independently of this arbor, for the purpose of setting the hand to the requisite minute on the dial. The cannon-pinion has 10 teeth, and impels a similar pinion, *g*, round also in an hour: this pinion *g*, called the *pinion of report*, has a pinion of 6 on its arbor, and is pivoted into the cock *h*, so that the small pinion of 6 also revolves in an hour. This pinion of 6 again impels the wheel *i* of 72 teeth in $\frac{72}{6}$ of an hour; *i. e.* in 12 hours: this 12-hour wheel has also a

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(1) Mr Adam Thomson, in his amusing and instructive little work on "Time and Time-keepers," (1842,) states that Tompion and Graham were buried in the same grave in the nave of Westminster Abbey. A slab bore the following inscription:—"Here lies ye body of Thomas Tompion, who died November 20th, 1713, aged 75. Also Geo. Graham, Watchmaker and F.R.S. whose curious inventions do honour to ye British genius, whose accurate performances are ye standard of Mechanic skill. He died ye 16th of November 1751, in ye 78th year of his age." Mr. Thomson feelingly remarks, "Watchmakers, the writer among the number, until prevented by recent restrictions, were in the habit of making frequent pilgrimages to the sacred spot: from the inscription and the place they felt proud of their occupation, and many a secret wish to excel has arisen while silently contemplating the resting-place of the two men whose memory they so much revered." The slab was removed in 1838, and a small lozenge of marble with the name "Tompion 1713," and "Graham 1751" substituted in its place.

(2) This figure is reduced, and the description abridged from one of the admirable articles on Clock and Watch work, in Rees's Cyclopædia.

tube surrounding the tube of the cannon-pinion, but in such a way that a third tube, attached to the bridge K, is interposed between the two tubes of the cannon-pinion and 12-hour wheel: the use of this third fixed tube is to prevent the friction of two tubes revolving in contact with such different velocities as 12 : 1. On the exterior tube of the 12-hour wheel the hour-hand is inserted; and it is evident that whenever the minute-hand carries the cannon-pinion round, the pinion of report *g* also moves the same quantity, and by means of the small pinion of 6 the wheel *i* must, at the same time, move $\frac{1}{12}$ of the same space, and consequently the 2 hands are so connected that one cannot move without the other, supposing them to be both fast to their respective tubes; but the hour-hand is put on the round part of its tube, and kept to it by mere friction, and therefore may be put to any hour without carrying the minute-hand round many revolutions, and yet, when once placed right, it preserves its relative velocity as though it were more firmly attached to its tube. I is the arbor of the seconds-hand, which revolves in a minute, and which measures the 120th part in its divided small circle on the face of the clock at so many vibrations of the pendulum, or at so many half-rounds. To the 12-hour wheel *i* is pinioned fast an indented spiral piece of metal, called the *snail*, which also revolves in 12 hours. Each indentation of the snail subtends an angle of 30° ($\frac{1}{12}$), so that one indentation, whether near to the centre of motion or far from it, is exactly the measure of an hour's motion of the 12-hour wheel. The steel piece *m n* is called a rack from the teeth on the cross piece *m*, the lower cross piece of which is called the *rack-tail*: the rack is movable on a pin or stud at the lower angular point, near which the horse-shoe spring *o*, called the *rack-tail spring*, presses to keep a pin on the remote end of this tail, against that indentation of the snail which happens to be contiguous to it. On the lever, between *m* and *n*, is a bend to prevent its touching the winding arbor F of the fusee belonging to the striking part: also at *m* is a strong steel pin projecting from the rack. Above the rack is a horizontal steel bar, *p q r*, movable on a stud at *r*, which is called the *hawk's-bill*, from the bill or angular piece at *q* that catches the teeth of the rack. The piece *s*, fixed to the protruding pivot of the wheel (next the pin wheel) near its lower extremity, and revolving with it, gathers up a tooth of the rack at each revolution, on which account it is called the *gathering-pallet;* the catch of the hawk's-bill having a contrary slope, gives way in the mean time, and comes back again by its own gravity. The pinion on this pivot driven by the pin-wheel (which has 64 teeth and 8 pins) has 8 leaves, and therefore revolves once every time that the hammer of the bell is lifted; but its gathering-pallet takes up a tooth of the rack at each revolution of its arbor, consequently a tooth of the rack is gathered up at every stroke of the hammer when the striking part is in motion. The angular piece, *t u v*, movable round an arbor, is called the *warning-piece;* its lower end, *v*, falls in the way of a pin in the small hour-wheel *g*, and its bent end *t* passes through an aperture, *w*, in the front plate of the frame, in such a position as to come in contact with a pin on the fly, which is therefore unable to revolve until this bent piece is lifted away from the pin. The bent end *t* also lies under the piece *s*, so that when it is lifted away from the pin on the fly it raises this piece and the hawk's-bill *q*. The action of the different parts may be thus explained: Whenever the hawk's-bill *q* is lifted from the teeth of the rack the spring *o*, pressing against a pin near its tail, makes it fall back till it meets with some obstacle to arrest its motion, which obstacle would be the pin of the pin-wheel in the front plate, if there were no other interposed before it had fallen so far back, but if the snail is in any other position than that wherein its nearest indentation towards the centre is contiguous to the pin of the rack-tail, the tail pin of the rack will fall upon the edge of the snail before the rack has fallen back to the pin *x*, and all the teeth of the rack will not, in this case, pass the catch of the hawk's-bill, but just so many as there are indentations or steps counted from the remote angular point of the snail to the step on which the tail-pin rests. In the position shown in the Figure the tail-pin is resting on the 6th step of the snail, which denotes that 6 strokes will be given by the hammer, or that 6 teeth of the rack are to be gathered up by as many movements to and fro of the piece *s:* but we see that only 5 teeth remain to be gathered up of the rack: hence we know that the clock has struck 1 out of 6, and is in the act of striking: the clock will therefore now continue to strike till the upper end of the gathering-pallet *s* falls on the projecting pin *m* of the rack, which will be as soon as the last tooth of the rack is drawn up to the hawk's-bill, in which situation the wheel Q cannot revolve any further till another hour has elapsed. After another hour is past, the pin of the wheel *g* will again elevate the warning-piece *v*, the bent end *t* of which will first be raised out of the way of the pin of

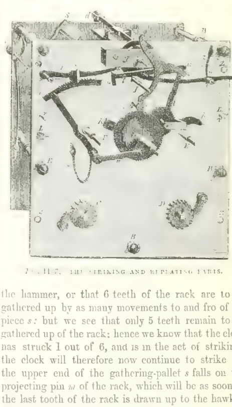

FIG. 11[illegible]. THE STRIKING AND REPEATING PARTS.

the pin-wheel, and the fly s will run on a revolution or two with a whistling noise, i.e. the clock will *give warning*; but the end p of the lock-hand has not yet been raised far enough by the pressure of the end t of the warning-piece to make the catch q clear the teeth of the rack; therefore the rack cannot yet fall back; presently, however, the hour-wheel g is lifted high enough by the continued motion of the pin; the rack then falls back till its tail-pin rests on step 7 (since the cannon-wheel has now arrived at the point of contact), and therefore 7 teeth of the rack pass the catch q in the fall of the rack, and the hour of 7 is now struck before the tail of the gathering pallet x takes again on the pin x of the rack, and stops the striking; at the same time the head of the warning-piece catches the pin of the fly and stops it; and in this way any number of hours will be struck by the hammer on the bell that the snail indicates which revolves once in 12 hours; and if any other cause than the pin of the hour-wheel g should lift the warning-piece within the hour, counting from warning to warning, the same number of strokes will be repeated, though it should be a hundred times or more. To convert this striking mechanism into a repeating mechanism, it is only necessary to add a lever y to revolve round a stud on the front plate of the frame at the point 7, with a slender spring z over it, to bring it back to its original situation, when the end placed under the warning-piece is elevated by depressing the exterior end, which may be done by pulling down a string attached to this end, as shown in the figure; and as often as the string is pulled, so often will the clock repeat the strokes of the current hour. The three-armed piece 1, 2, 3, called *strike or silent*, is differently made in different clocks. In our figure it is movable on a socket pivoted to the end 3 of one of its arms, round a stud in the front plate of the frame, and as the socket has scarcely any shake, the other two ends, 1 and 2, move always in the same plane: at the end marked 1 is a pin projecting above the upper circumference of the face or dial of the clock, so that it may be moved to the right or left at pleasure: the end marked 2 has a slope like a wedge on that side which is next to the plane of the front plate, and the end of the arbor of the warning-piece projects so far as to touch the inclined plane: this arbor of the warning-piece has some freedom in the direction of its length within the frame, and its posterior pivot passes between the prongs of a forked spring, which, resting against the shoulder of the pivot, pushes it close to the interior side of the front plate of the frame, where a similar shoulder stops it: when the pin at 7 is pushed to the right, the wedge of the end 2 pushes the arbor back, and the end t of the warning-piece being carried with it is brought nearer to the frame than it otherwise would be, falls in the way of the pin of the hour-wheel g, and the clock consequently strikes the hour regulated by the snail; but when the pin at 1 of the strike or silent is pushed to the left, the end 2 is withdrawn from the pivot of the arbor on which the warning-piece is fast, the spring in the frame pushes it forward so far that the end t of this warning-piece is clear of the pin of the hour-wheel g, which wheel, therefore, continues to revolve from hour to hour in a state completely detached from the mechanism of the striking part. In clocks which have no seconds-hand, there is a hand movable in a small circle in the dial, which answers the same purpose as the pin at 7.

The machinery for striking *quarters* is similar to that for striking the hours, only there are two hammers instead of one, and an additional set of pins on the striking-wheel for raising them. For what are called *dingdong* quarters 2 bells are used, and the striking-wheel has 2 sets of pins on its opposite sides, which raise the 2 hammers alternately. If there are four or more bells, the rim of the striking-wheel is spread out so as to form a *cylinder* or *barrel* with pins sticking out from it like the barrel of a musical-box, and the hammers, which are all set on one axis, are raised by these pins.

Alarum. If the pendulum be taken off a clock with a recoil escapement, it will beat about as quickly as the bell is struck in an alarum; and the striking in an alarum takes place in the same way as if a double hammer were put on the end of the crutch of a recoil escapement long enough to reach the inside of the bell. In order to let off the alarum, the letting off pin is made movable on the wheel which carries it. "If the common letting-off pin were made movable upon the hour-wheel, we might make the clock strike when the long-hand is at 50 m. instead of 60 m.; and in like manner, if we put a letting-off pin for the alarum on a cap or *key*, which fits tightly on to the socket of the 12 hour wheel, we can make it let off with as much accuracy as is required at any portion of the twelve hours we please. The key which carries the pin, has its socket prolonged forward so as to carry a small dial or hour-circle under the hour hand, which always travels round with it; but the key does not fit so tightly that it cannot be moved by the hand so as to make a pointer in the hour hand point to any time we like on the alarum dial, and then it will let off at the time so indicated. There is no occasion for any stopping apparatus beyond a single lifting piece and a pin in the striking-wheel, which rests against the end of the lifting piece when it is not raised high enough to let the alarum go. The string of the weight is attached to a barrel, exactly like a recoil scape-wheel, either of the crown-wheel or the plain kind, and when it is let off it runs till it is down. Of course it must not be wound up until within 12 hours of the time when it is intended to strike."

The Watchman's Clock, or *Tell-tale Clock*. In this clock there are a number of pins sticking out round the dial, one for every quarter of an hour, and it is the duty of the watchman on the premises, where such a clock is kept, to go to the clock every quarter of an hour, and push in the proper pin, thereby proving to the inspector, next morning, that he was vigilant during the night. Each pin admits of being pushed in during a few minutes only, and if the time be neglected it will be found sticking out, and will show the exact time when the watchman was negligent. In a tell tale clock in one of the lobbies of the House of Commons the face and pins are enclosed behind a glass, and outside the clock-case is a handle communicating with a small lever standing over a part of the circle in which the pins move; and as the pins are carried round in a sort of movable dial, the effect of pulling the handle is to push the pin, which comes under the lever every quarter of an hour. In these clocks the pins are made to pass over an inclined plane some hours after they have been pushed in, and in this way are pushed out again.

In Mr. Denison's "Rudimentary Treatise" will be found an interesting chapter on Church clocks, together with an account of the negociations for the Great Clock for the New Palace at Westminster. One of the most remarkable clocks in London is that at the Royal Exchange, the working parts of which are represented in the full-page engraving which is to accompany this article. When Mr. Dent was engaged by the Gresham Committee to construct for the new Royal Exchange as perfect a clock as the state of the art allowed, he took the advice of, and submitted the results of his labours, to Professor Airy, the Astronomer-Royal. In the construction of this clock the trains are contained within a simple but strong cast-iron framing, in which every strain is so completely self-contained, that the operation of fixing the clock is easy, nothing more than a firm and level base being required for the framing. Hollow iron drums are used instead of wooden cylinders for the driving barrels, and wire instead of hempen ropes are employed for suspending the weights. The first of these improvements ensures a more permanent accuracy of form, and the use of wire-rope allows a smaller cord to be used, thus preventing the necessity for over-lapping. In this way the weight exerts the same force to turn the barrel, which is not the case with a thicker rope covering the barrel in 2 or 3 layers. In this clock the hands are driven, and the hammers of the striking part raised, directly from the axis of the driving-barrel, without the intervention of wheels and pinions. Our engraving will show the rods and bevil-gear by which this clock indicates the hour on the *four* dials of the four external faces of the turret. The pendulum of this clock is compensated, and the first stroke of the hour is true to a second. For this purpose the lever and hammer are removed to their greatest distance before the time of striking, and the end of the lever remains delicately poised upon the rounded point of the projecting tooth of the pin-wheel until the exact time for striking has arrived, when it is released on the instant. The pendulum is thus described:[1]—"The centre rod of the pendulum is of steel, and is sufficiently long to pass completely through the bob or weight, which, however, is not immediately attached to it. Upon the bottom of this rod is fixed a nut, by turning which the length of the pendulum may be nicely adjusted, and upon which stands a hollow column of zinc, through which the steel rod passes freely. On the top of the zinc column is a metal cap, from projecting portions of which descend 2 slender steel rods, to the lower ends of which the weight, which is a hollow cylinder of iron, capable of sliding freely upon the zinc column, is suspended. Thus, while both the central steel rod, and the two smaller steel rods by which the weight is suspended, expand downwards upon any increase of heat, the position of the weight in reference to the point of suspension of the pendulum remains nearly the same, because the zinc column, though shorter than the central steel rod, expands to an equal extent upwards, and consequently raises the weight just as much as it is depressed by the lengthening of the steel rod. As the pendulum weighs nearly 4 cwt., the operation of setting it so that its vibrations might be correct to within a fraction of a second, was a matter of extreme difficulty. This was met by a contrivance suggested by Mr. Airy: the clock being started at a very small losing rate, a slender spring, so mounted as to touch the pendulum slightly, (and thus by slightly diminishing the amplitude of the arc cause the clock to gain,) was brought in contact with the pendulum-bob nearly at the centre of percussion, by means of a line in the clock-room. By this means the beats of a large turret-clock may be brought to coincide perfectly with those of a chronometer by which it is set. The regulating screw, by which the length of the pendulum is adjusted, is not moved for the correction of small errors in the rate of going, such being provided for by the use of small supplementary weights laid upon each side of the top of the pendulum-bob, which weights may be applied or removed without stopping the clock."

This clock has a remontoir escapement, and the pallets are jewelled with large sapphires. Mr. Airy's construction of the going-fusee is also introduced for maintaining the clock during the winding.

ELECTRIC CLOCKS. About the year 1840 Professor Wheatstone exhibited in the apartments of the Royal Society in Somerset House an *electro-magnetic clock*, the object of which was stated to be to enable a single clock to indicate exactly the same time in as many different places distant from each other as may be required. Thus in an astronomical observatory, every room may be furnished with an instrument of simple construction and at small cost, which shall indicate the time, and beat dead seconds audibly with the same precision as the standard astronomical clock with which it is connected; thereby obviating the necessity for having several clocks, and diminishing the trouble of winding up and regulating them separately. In like manner in public offices and large establishments, one good clock will serve the purpose of indicating the precise time in every part of the building where it may be required, and an accuracy insured which it would be difficult to obtain by independent clocks, without referring to the cost. In the clock exhibited, the parts connected with the maintaining and regulating power were dispensed with. It consisted simply of a face, with its second, minute, and hour hands, and of a train of wheels communicating motion

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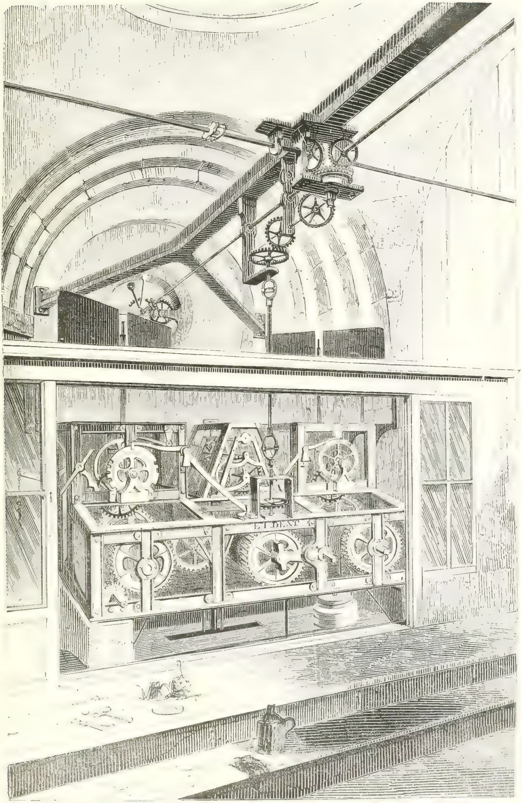
(1) Penny Cyclopædia Supplement, Article "Horology."



HOROLOGY.—WORKING PARTS OF THE CLOCK AT THE ROYAL EXCHANGE, LONDON.

from the arbor of the seconds hand to that of the hour hand, in the same manner as in an ordinary clock train. A small electro-magnet was made to act upon a wheel placed on the seconds arbor, in such a manner that whenever the temporary magnetism was either produced or destroyed, the wheel, and consequently the seconds hand, advanced $\frac{1}{60}$th part of its revolution. Thus, by alternately completing and breaking the electric current every second, the apparatus described would perform all the usual functions of a perfect clock. The method of connecting this apparatus with a clock so as exactly to repeat the movements of its hands was as follows:—On the axis which carries the scape wheel of the primary clock was fixed a small disk of brass divided on its circumference into 60 equal parts; each alternate division was then cut out and filled with a piece of wood, so that the circumference consisted of 30 regular alternations of wood and metal. An extremely light brass spring screwed to a block of ivory or hard wood, and not connected with the metallic parts of the clock, rested by its free end on the circumference of the disk. A copper wire attached to the fixed end of the spring proceeded to one end of the wire of the electro-magnet; while another wire, attached to the clock frame, was continued until it joined the other end of the wire of the electro-magnet. A constant voltaic battery of small size was interposed in any part of the circuit. Hence it will be seen that by this arrangement the circuit is periodically made and broken in consequence of the spring resting for one second on a metal division, and the next second on a wooden division. The circuit may be extended to any length, and any number of electro-magnetic clocks may be brought into sympathetic action with the standard clock.

Mr. Bain, Mr. Appold, and others, have also produced various forms of electric clocks, in which the current from the voltaic or *earth*[1] battery is made to supply the place of the spring or weight commonly used as the maintaining power. In these and other ingenious applications of electro-magnetism as a maintaining power to clocks, the attraction and repulsion of magnets have been brought to bear directly on the pendulum, the bob of which is a coil of insulated wire, through which the electric fluid is transmitted at intervals. While the current is being transmitted, the pendulum is attracted by the magnet and made to produce an oscillation, during which a pin, projecting from the pendulum rod, pushes a sliding bar from off certain conducting surfaces upon which it rests, and thus breaking contact the electric coil or bob loses its magnetism, and thus ceases to be attracted by the permanent magnet, which a moment before had deflected it; it, therefore, falls back into the vertical, and by its momentum performs the opposite oscillation; but in doing this, the pin again comes in contact with the sliding bar, and restores it into the position in which the circuit is completed; the coil is again electrified and consequently again in a condition to be attracted by the magnet; in swinging up to it contact is again broken; attraction again ceases; the pendulum swings back again, and in this way the pendulum is kept vibrating, and by its vibrations communicates motion to the escape wheel or other contrivance, and thence to the clock train.[2]

One of the latest arrangements of the electric clock is that contrived by Mr. Shepherd, of London, whose clock was shown on a large scale at the Exhibition. In applying electricity to produce the vibrations of the pendulum, the amount of power must be constantly varying with the variations of the battery, and it is of course impossible to obtain correct chronometrical results under such circumstances. Now it occurred to Mr. Shepherd that if, instead of applying the magnetic power directly to the pendulum, it were employed, on the principle of the remontoir escapement, to bend a spring to a certain fixed extent during each vibration, which spring in unbending should give the necessary impulse to the pendulum, the pendulum would thus be independent of variations in the electro-magnet, the function of which would be simply to bend the spring.

The three following figures (the drawings for which have been kindly supplied to us by Mr. Shepherd) will enable us to convey a correct idea of this ingenious invention, which, unlike the previous electric clocks, aims at being itself a perfect time-keeper. It should be stated that in this arrangement the *pendulum*, the

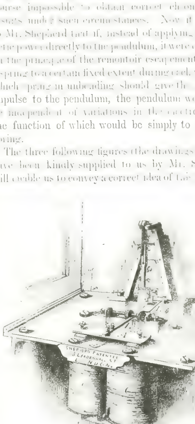


Fig. 1184.

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[1] The earth battery, as usually made, consists of a large plate of zinc and another plate of copper, or a quantity of coke, buried at a certain distance asunder in damp earth. The moisture of the earth acts on this voltaic couple as the exciting fluid, and a feeble but very constant current is produced by this arrangement.

[2] In our articles ELECTRIC TELEGRAPH and ELECTRO-MOTIVE MACHINES, a variety of contrivances for producing motion by electricity, and for closing and interrupting the current, will be found described. In the article ELECTRO-MAGNETISM various forms of Voltaic battery are described.

clock train and the *striking part* has each its own separate and distinct system of electro-magnets and voltaic battery, so that the pendulum may continue to vibrate although the clock train be at rest, the train being set in motion by its own electro-magnets under the regulating influence of the pendulum. The striking part is also under the control of the pendulum and the train, although moved by its own electric power. It is one of the peculiarities of Mr. Shepherd's clock, that the pendulum does not depend for its motion, as in ordinary clocks, upon the clock train, nor does it constitute the maintaining power, as in Mr. Bain's clock. The pendulum may be quite detached from the other portions of the clock, and may, indeed, be used for a great number of clocks in simultaneous action.

Fig. 1184 shows the pendulum Q Q suspended from a rectangular framing and passing through a hole in the bed plate. M is a horse-shoe of soft iron each limb of which is surrounded by a coil of wire, C C, one of the extremities of this compound coil terminating in the metal bed plate, and the other in the rectangular framing at I, in a slight spring tipped with platinum and insulated by an ivory mounting. The swinging of the pendulum to the right completes the circuit, and converts M into a powerful magnet. The two ends or poles of this magnet pass through the bed plate and rise a little way above its surface. A is an armature of iron which is attracted down to the poles of the magnet whenever an electric current is circulating in the coils, C C, and is detached therefrom by a weighted lever L L' as soon as the current is interrupted. The lever L L' is attached at right angles to a short axis, the extremities of which move in two brackets, so as to raise the lever a little way above the bed plate; to the extremity of the arm L' is fixed a weight, which is better shown at W, Fig. 1185, to which we will now refer, this figure representing on a larger scale similar parts of Fig. 1184. (In this figure, however, L should be L'.) E E' is called the *impulse spring*, and D D' *a detent or catch* for holding this spring when bent by the action of the magnet. Now the action is as follows:—Supposing the pendulum to have swung to the right by a force which we will explain presently, it touches the insulating spring I and closes the circuit; whereupon M becoming magnetised by the passage of a current through C C, the armature A is attracted down, the effect of which is to move the weight W up, and in doing so it will raise the arm E' of the spring or right-angled lever E E', which moves upon a centre at its right angle, and in doing so will lock another right-angled lever D D', leaving it in the position shown in Fig. 1185. But by the time the detent is locked, the pendulum, which we have supposed to have swung from left to right, falls back into the vertical by the action of gravity alone, and by its momentum is carried to the left; contact is broken at I; M ceases to be a magnet; the weight W falls down and raises the armature A from the magnet, leaving E' free to fall when E is unlocked at D. Meanwhile the pendulum goes on swinging to the left, and soon causes the banking screw T to strike against the discharging pallet D' and unlock the detent: the arm or lever E thereupon falls down upon the impulse pallet F, and gives the pendulum its impulse back again from left to right with a force just sufficient for it to continue its vibration. Thus it will be seen that the periodical falling of the spring E E' gives the impulse to the pendulum from left to right; that the making contact while the pendulum is at the right has the effect of restoring the spring E E' to its position preparatory to another fall: that the swinging of the pendulum to the left breaks contact, and by raising D allows E E' to make another fall. In this way the action proceeds, the electro-magnet being used for the sole purpose of restoring the spring to the position shown in Fig. 1185; it evidently does not matter how much the magnet M may vary in intensity provided it be not too weak to pull down the armature A, and it is an advantage to employ an excess of magnetic power in machines of this kind.

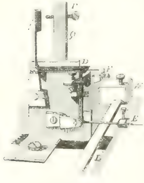

Fig. 1185.

In order to move the clock train and the hands H H, Fig. 1186, on the dial plate, there are a pair of pallets P, taking into the teeth of the escape-wheel at right angles, to which are fixed two or more bar magnets B B. Immediately under or over each of the poles of these bar magnets is the pole of an electro-magnet M M. These electro-magnets are caused alternately to attract and repel the bar-magnets,

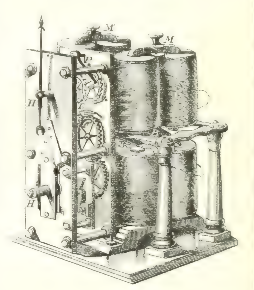

Fig. 1186.

thereby imparting an oscillating motion to the pallets, which act in the teeth of the escape-wheel E, and drive it forward: the motion thus produced is carried through a train of wheels in the usual way. In producing the electric currents required, two contact-springs and two batteries are employed: the contact-springs are mounted on an ivory bracket, one spring on each side of the pendulum-rod, with which their points make contact close up to the centre of motion, at the end of the vibrations of the pendulum each way. The batteries are arranged in connexion with these springs, so that the circuit of each battery shall be in a contrary direction to the other. Consequently, as the pendulum vibrates to the right, it completes the circuit of one battery; the electricity passing through the coils of the electro-magnets, they cause one oscillation of the bar-magnets. On the opposite vibration of the pendulum, it makes contact with the opposite spring, the battery in connexion with this being arranged in a contrary direction to the former; the electricity passes through the coils of the electro-magnets in a contrary direction, causing an opposite oscillation of the bar-magnets, and consequently of the pallets, which, operating on the teeth of the escape-wheel, drive it forward.

Mr. Shepherd in his paper on this subject, read before the Society of Arts 26th February, 1851, states, that this method of using attraction and repulsion has two advantages. It admits of electro-magnets being used of such size, that about 2,000 feet of wire may be wound upon them, whereby a great saving in the batteries is effected. It also insures great certainty in the action with the smallest possible power, since the power applied to move the pallets is nearly equal throughout the extent of their motion. By using two batteries, reversed currents may be produced with only one spring on each side of the pendulum, while to reverse the connexion of one battery, two springs would be required, which would be more disadvantageous.

The application of the electro-magnetism to the striking part is thus effected: the escape, or seconds-wheel is furnished with a projecting pin, which is thus carried round once in a minute. The minute-wheel, carrying the minute-hand, has a similar pin, which only completes its circuit once in the hour; in consequence of which the two pins are in conjunction only once in that time, namely, exactly at the hour. On an arbor in the frame of the clock is fixed an elastic arm, which is insulated from the arbor by an ivory bush. This arm carries at its extremity a small pad or table of platinum, on which, if it be sufficiently raised, the pin of the escape-wheel rubs in passing. The arbor also carries a rigid arm in such a position that the pin in the minute-wheel lifts it as it passes each hour; but the arm cannot be raised without the elastic arm, also carried by the arbor, being lifted, by which the platinum table at its extremity comes into contact with the pin in the seconds-wheel,—an occurrence which takes place at the hour, the hands being properly adjusted to that end. By so doing, it completes the circuit of a battery, which has one pole connected with the clock-frame and the other with the coils of the electro-magnet. Now, the only break which exists in this circuit is at the small platinum pad; when, therefore, at the completion of each hour, the pad and the pin are in contact, the circuit will be rendered complete. The magnet is thus rendered active, and by its attraction draws down the armature. The armature is situated at one end of a lever, the other end of which carries a detent, which is received into the notches of the locking-plate. When the armature is drawn down (in other words, when the circuit of the battery is complete at the end of each hour), the detent is drawn out of the notch, and the locking-plate left free to revolve. The raising of this detent forms a contact between a wire from another battery and the clock-frame. This battery actuates a magnet, which works the actual striking apparatus. The circuit is completed through the clock-frame and through the bar-magnets, formerly described as oscillating once in every second, one end of which as it rises touches a stud immediately over it, at the end of the other wire of the battery. This magnet, being therefore rendered active once in every two seconds, while the locking-plate is free, alternately attracts and repels one end of a lever, to which is attached the hammer; the other end taking into a ratchet and click arrangement, which allows the striking to continue as long as the locking-plate is free.

We have already seen that the inventor of the electric clock in 1840, proposed by this instrument to publish the precise time in every part of a large observatory, or other establishment. By an extension of the idea it is proposed in 1852 to connect all the railway stations in the kingdom with a great central clock, placed in communication with the Greenwich electric clock, which is so constructed as to transmit time-signals every hour and half hour throughout the day all over the kingdom. These signals will be received at the central telegraph office in London and be despatched down the different lines of railway in succession, one at one hour and another at the next hour. At one o'clock no time-signal will be sent, but at that hour precisely the electric clock will drop the time-ball at the Royal Observatory, to enable ships in the river to adjust their chronometers. Time-balls will also be erected on the roofs of the telegraph offices. As it is now becoming customary to set all the clocks in the kingdom to Greenwich instead of local time, the carrying out of this idea will be of great value. By means of the electric clock it is also proposed to transmit time signals from one observatory to another, and thus test some interesting problems respecting longitude, &c.

HORSE-HAIR. See HAIR.

HORSE-POWER. A term introduced by Watt, to enable him to determine what size of steam-engine should be sent to his customers on their informing him how many horses they were accustomed to employ to do the required work. It was found by experiment that the average force exerted by the strongest horses at one of the London breweries was equal to 33,000 lbs. raised 1 foot high in a minute, and this was taken as equivalent to 1-horse-power. Since the time of Watt, however, the capacity of cylinder answerable to a horse-power, and the pressure on the piston, have been increased, so that at the present time a horse-power is a mere conventional unit for expressing a certain size of cylinder without reference to the power exerted. See STEAM-ENGINE.

HOSIERY. See WEAVING.

HOT-BLAST. See IRON.

HYDRATES, combinations of water with other oxides. For example, when a small quantity of water is poured upon lime (which is oxide of calcium), a portion of the water combines therewith, forming a bulky white powder, which is hydrate of lime (CaO, HO). In the formation of hydrates the action is often very irregular, and the temperature is greatly raised, as in the slaking of lime, the example just given. The attraction between the water and the second body is often so strong that it cannot be separated by the application of heat. The hydrates of potash, of soda, and of phosphoric acid, are examples of this; so also is oil of vitriol, which is a hydrate of sulphuric acid.

HYDRAULICS. See HYDROSTATICS and HYDRODYNAMICS.

HYDRAULIC-PRESS. See HYDROSTATICS.

HYDRIODIC ACID. See IODINE.

HYDROCHLORIC ACID. (HCl. 36·5). This important acid belongs to the class of hydrogen acids or hydracids, which do not exist in salts. It has long been known in solution in water under the names of *spirit of salt*, *marine acid*, and *muriatic acid*, (from *muria*, sea-salt.) In its pure form it is a gas, which may be formed by mixing together one volume of hydrogen and one of chlorine, and exposing the mixture to the light of day, when the gases slowly combine, and produce two volumes of hydrochloric acid gas: but if exposed to the direct rays of the sun, the gases combine with an explosion: such also is the case when an electric spark is passed through the mixture. Hydrochloric acid gas may also be easily prepared by heating in a flask, fitted with a cork and a bent tube, a mixture of common salt and sulphuric acid diluted with water.[1] The gas, which must be collected over mercury, is colourless; it produces a white cloud or fume in the air in consequence of its strong affinity for moisture; it has an acid suffocating odour, and can be liquefied under a pressure of 40 atmospheres. Its density is 1·247: it is so soluble in water that at the temperature of 40° that liquid dissolves about 480 times its bulk of the gas. The solution is powerfully acid.

The muriatic acid of commerce is prepared by decomposing common salt with sulphuric acid and receiving the gas in water. The materials employed, and the products, may be stated in another form:—

1 equivalent of chloride of sodium	58·5
1 equiv. of sulphuric acid (oil of vitriol containing 1 equiv. of water)	49
	107·5
PRODUCTS.	
1 equiv. of sulphate of soda	71
1 equiv. of hydrochloric acid	36·5
	107·5

In order to condense the hydrochloric acid, 6 equivalents of water = 54 are used, which, added to the equivalent of acid = 36·5, give 90·5 of liquid acid: so that supposing the operation were conducted without loss, 60 parts of common salt will give 71 of sulphate of soda, and 90½ of muriatic acid.

There are several methods of preparing the acid on a large scale. In places where glass can be had at moderate cost large glass retorts are used. The salt is first introduced, and then the acid, in such a way, by means of a long funnel, so as not to soil the neck. The beak of the retort is then introduced into a large globular receiver D, Fig. 1187, from which a tube passes into a Woulfe's bottle E,[2] and this is connected by a bent tube with a second bottle, the second with a third, and so on; by which means the acid may be obtained of different degrees of purity. The first bottle, which contains no water, retains the

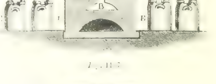

Fig. 1187.

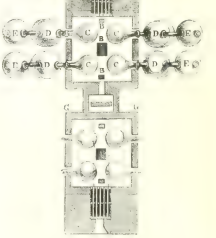

Fig. 1188.

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[1] The reaction is thus explained:—

Chloride of sodium { Chlorine — Hydrochloric acid.
{ Sodium
Water . . . . { Hydrogen
{ Oxygen
Sulphuric acid . . . . — Sulphate of soda.

[2] Woulfe's apparatus is more particularly described in the art. DISTILLATION, vol. i. p. 167.

impure portions of the acid: and the vapour then passes from it into the second, third, and other bottles, which contain a supply of water for condensing it. That portion of the vapour which escapes condensation in the bottles is passed by a tube into a vessel of water. The condensation is instantaneous, or nearly so, but as the temperature rises less gas is absorbed, hence the condensing vessels should be kept cool. The retorts, d, d, d, d, Fig. 1188, are arranged in the vault of a furnace, b c, in two rows, as shown in Fig. 1188, and are heated by the hot air from the furnace a, which, by an arrangement of the brickwork, is made to circulate round the retorts on its passage to the chimney g, and in order that the draughts of the two contiguous furnaces may not interfere with each other, the chimney is in some way or is divided by a partition wall.

Muriatic acid is also manufactured on the large scale by using iron cylinders for the retorts. Alkali works, in which common salt is decomposed for the manufacture of carbonate of soda, produce enormous quantities of muriatic acid as a waste product, and, passing up the chimney, it may be seen condensed by the atmospheric moisture hovering over it in the form of a white cloud, which, wafted away by the wind, produces a corrosive rain, which ruins the vegetation of the surrounding district. Of late years, however, this acid has been turned to profitable account. [See SODIUM.]

When the solution of muriatic acid gas is pure, it is transparent and colourless: when saturated with the gas it has a sp. gr. of 1·21, and contains about 42 per cent. of real acid. The commercial acid is impure: it has a yellow colour, and contains sulphuric acid, chloride of iron, and organic matter. It may be purified by mixing with water and distilling.

HYDROCYANIC ACID. See PRUSSIAN BLUE.

HYDROGEN, (from ὕδωρ, water, and γεννάω, to produce,) one of the constituents of water. Its symbol is H, and its atomic or combining number 1. It may be procured by passing vapour of water through an iron or porcelain tube, containing, in the middle part, a quantity of iron turnings heated to redness by fixing the tube across a furnace. The oxygen of the vapour of water combines with the iron, while the hydrogen passes off in a permanent form, and may be collected and examined.

Hydrogen may be conveniently collected by the action upon each other of zinc, sulphuric acid, and water: the oxygen of the water unites with the zinc, forming oxide of zinc, which is instantly dissolved by the acid, while the hydrogen of the water is set free in the gaseous form.

Hydrogen, when quite pure, is colourless, tasteless, and inodorous. It is inflammable, burning when kindled, with a pale-yellowish flame, giving out much heat, but very little light, the result of the combustion being water. It is not soluble in water, and it has never been liquefied. It is the lightest substance known, its sp. gr. being between 0691 and 0695. Under ordinary pressure and temperature 100 cubic inches weigh 2·14 grains.

Although hydrogen is of immense importance in the economy of nature and in chemical science, it has but very few applications in the useful arts. Perhaps its most useful industrial application is for what is called *autogenous soldering*. See SOLDERING. It is used in restoring to the metallic state copper turnings which have become oxydized. For this purpose they are heated in a tube, and a stream of hydrogen passed over them, which combines with the oxygen and revives the copper. Hydrogen may also be used for filling balloons in places where coal-gas is not to be had, and it may be employed in conjunction with spongy platinum in an instantaneous light apparatus, Fig. 1189, the construction of which is as follows. It consists of a glass vessel A, into which passes the stem of a glass globe B, fitting air-tight at the neck of A. B is also furnished with a tight stopple s. From the side of A proceeds a short pipe furnished with a stopcock C, opposite the jet of which is mounted, upon a bent wire, a ball of spongy platinum. Upon the stem of B a piece of thick zinc tube z is fixed by means of a ring of cork at the bottom. The vessel A is about 3 parts filled with water acidulated with sulphuric acid. On putting the B in into the bottle, opening C, removing s, and turning away p, which may be done by means of the joint, the action is as follows:—Hydrogen gas will be generated, and rising to the top of the vessel A, will pass out through C, and escape, taking with it the air left in the vessel. If C be now closed the hydrogen will accumulate in A, and by its pressure force the acid water up the pipe into the globe B, gradually uncovering the zinc until it is left quite dry, when of course the generation of the hydrogen ceases. If now we bring the spongy platinum round before the jet C, and open the stop cock, the hydrogen streaming upon the finely divided platinum, the latter will cause the hydrogen to unite with the oxygen of the air, the effect of which will be to raise its temperature to redness, and thus to set fire to the jet of gas issuing from the stop cock. From this ignited jet a taper or a match paper may be lighted. While the gas is issuing from C, acid descends from B into A, and gradually covers the zinc; thereby keeping up the supply of gas; but on closing C the gas drives the acid back again into B, and the zinc is again left dry. This apparatus may be made ornamental in form, and small in size.

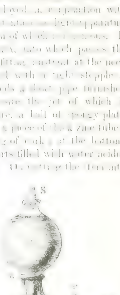

Fig. 1189.

HYDROMETER. See GRAVITY, SPECIFIC.

HYDROSTATICS and **HYDRODYNAMICS,** form the third and fourth of the great divisions of the Science of Mechanics. The one, which considers the laws of water in a state of rest, is derived from ὕδωρ, water, and στατὸς, standing still; and the other, which takes account of the laws which regulate water in a state of motion, is from ὕδωρ, and **δύναμις**, force. The latter is also termed HYDRAULICS.

The properties of liquids are always modified by the action of two forces; viz. that of weight, or the attraction of gravitation, to which they, in common with matter of all kinds, are subject; and, secondly, molecular attraction, which must act differently in liquids and solids, although we have no means of determining in what this difference consists. We can readily form an idea of the distinct action of each of these forces, for we can imagine a mass of water ceasing to be heavy without ceasing to be liquid; such a mass would neither fall nor flow when turned out of the vessel containing it, and indeed it would not require for its equilibrium to be sustained by the ground, or even by a vessel; and yet such a mass of weightless fluid would display a number of remarkable properties, the most important of which would be equality of pressure in all directions; that is to say, the liquid would transmit equally, and in all directions, any pressure exerted on its surface. For example, let *a b c d e f*, Fig. 1190, be a vessel containing a liquid supposed to be without weight, and P a solid piston, which exactly covers its surface. If the piston be also without weight, it is clear that the liquid experiences no pressure, and that if a hole were made in the vessel no portion of the liquid would flow out. Now, suppose that the piston be loaded with any given weight, say 100 lbs., it will of course tend to sink down into the liquid, and it would do so unless the liquid itself opposed such a tendency. Whether the liquid be compressible or not, the result is the same, for the liquid must either become annihilated, or it must bear up the weight of 100 lbs. If we divide the liquid into any number of layers, the uppermost layer, which is in contact with the piston, and sustains it, also sustains the whole of the weight, and would of course descend unless supported by the layer immediately beneath, which receives from the one above it as much pressure as that one receives from the piston. So also the second layer presses upon the third, and in this way we may go on until we arrive at the bottom of the vessel, which we shall find has to sustain the pressure of the 100 lbs. exactly as if the weight and piston were placed there instead of being transmitted by the liquid. Now, as this pressure of 100 lbs. is borne by the whole of the base of the vessel, it is evident that one-half of the base sustains only 50 lbs., and that one-hundredth part of the base sustains only 1 lb. We see, then, from this illustration, 1st, That the pressure is transmitted by horizontal surfaces from the top to the bottom of the vessel without any loss of effect; 2d, That the pressure is equal at each point; 3d, That it is proportional to the extent of the surface under consideration.

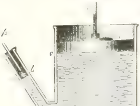

Fig. 1190.

So far we find no difference between a liquid and a solid, but the peculiar characteristic of liquids is, that the same effects are produced on the *sides* of the vessel as on the base. If a lateral opening be made in any direction, as at *a b*, the liquid will spirt out; and if the opening thus made be of the same size as the piston P, it will require a force equal to 100 lbs., to prevent the water from spirting out; if this side opening be only one-hundredth of the area of the piston, the water may be kept back with the force of 1 lb. If a hole be made in the piston, the liquid will spirt upwards, proving that the piston also sustains a pressure similar to that on the base and sides of the vessel. Indeed, this necessarily arises from the principle of action and reaction. It will be seen that liquids transmit equally, and in all directions, the pressures exerted on any part of them, so that every surface which they touch receives (and must return) a pressure proportioned to its area. Thus, if the area of the piston P be, as we have supposed, 100 times that of the piston *p*, it will require a pressure of 100 lbs. on P to balance 1 lb. on *p*. Thus we have another simple machine, like those commonly called MECHANICAL POWERS. And this *hydrostatic power*, no less than the others, depends on the principle of virtual velocities [See MECHANICS]: for it is evident that if the piston *p* be pushed in through any given distance, the piston P, which is 100 times larger will be thrust out only $\frac{1}{100}$ of that distance, so that whatever may be the gain of power, it is procured by an equivalent loss of motion. Used as a press (Bramah's press) this machine has some great advantages over the wedge or the screw, as its mechanical efficacy can evidently be increased to almost any extent without any proportionate increase of friction or complication of parts.

Now it must be evident that this property can be in no way altered by conferring weight on the liquids under consideration, except that additional forces arising from the mutual weight and pressure of the particles have to be taken into account. Whence it follows, that in order for a liquid to be in equilibrium, two conditions are necessary; first, every point of its surface must be perpendicular or normal to the force which acts upon it; and, secondly, each individual particle of the liquid must experience equal pressures in all directions.

With respect to the first condition of equilibrium, let us suppose that the surface is not perpendicular to the force which acts upon the liquid particles; that this surface follows the direction *a c d e*, Fig. 1191, while the force acts in the direction of the vertical lines V V. In such case a horizontal layer *b d* must be pressed by the weight of all the particles above it; and this pressure being, as we have seen, transmitted laterally, the molecule *d*, for example, would be thrust out by this lateral pressure, since there is no counterbalancing pressure on the opposite side; it is thrust aside, and another particle occupies its place, which, in its turn, is also thrust aside until at length

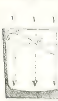

Fig. 1191.

the particles forming the curve *a c d*, have fallen into the depression *d c*, and the whole surface has become horizontal. The same process would take place with any other portion of the liquid above the horizontal surface, and there can be no equilibrium until there are no more particles to descend; when such is the case, they are all ranged in a plane normal to the force.

From the principle of equal pressures, as well as from the first condition of equilibrium in liquids, many important consequences are obtained. For example, the pressure of water and other liquids upon a given surface, is in proportion jointly to the magnitude of that surface and to the mean height of the liquid above that surface.[1] This truth is readily understood in the case of a cylindrical vessel, such as No. 1, in Fig. 1192, but it is not so evident in the vessels No. 2 and No. 3. All three vessels contain very unequal quantities of water; they differ in every respect except being of equal height and base; and in each case the same amount of pressure is exerted on the base without any regard to the bulk of the water. Hence we may estimate the pressure of a fluid upon the base of the containing vessel by multiplying its height into the area of the base, and this product by the density of the fluid. In the vessel No. 2 it will be seen that the bottom bears only the column of fluid denoted by the dotted lines, and which is exactly equal to the whole fluid in No. 1. But however paradoxical it may appear, it is no less true, that the base of No. 3 bears a pressure exactly equal to the same weight of fluid, although the whole vessel does not contain so much.

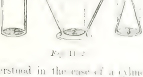

Fig. 1192.

Fig. 1193.

Some curious results may be obtained by the operation of this law. Let a vessel, A, Fig. 1193, full of water, have a slender tube, B, screwed into it: on filling the tube with water to a certain height, the vessel will immediately burst; and the height of the fluid necessary to effect this result will be exactly the same, however large or however small the tube may be; so that the weight of a single ounce of water, if piled high enough, may burst the strongest vessel. Suppose the bore of the tube to be one-twentieth of an inch, then whatever pressure is transmitted through it, an equal pressure will be borne by every space one-twentieth of an inch in diameter throughout the interior of A. Now a square inch contains about 530 such spaces; so that an ounce of water poured into such a tube would exert a pressure of 530 ozs., or 33 lbs., on every square inch of A; a force which few vessels, except steam boilers, are made capable of resisting.

Thus the whole interior surface of a vessel is subject to an enormous pressure in consequence of the manner in which liquid pressure is transmitted. And not only the interior surface, but the liquid particles also in every part of the vessel, are subject to corresponding pressures. In the interior of the liquid mass contained in the vessel shown in Fig. 1194, let us imagine a layer, *l l*, parallel to the surface S S. All the particles of this layer are evidently pressed by the mass of liquid above them; they are, as it were, under the pressure of a liquid cylinder, S S *l l*. But it is important to observe that this pressure from above, downwards, is, by the principle of action and reaction, exactly equal to that from below, upwards; and the separate molecules of this layer *l l* are held in equilibrium by these equal and opposite pressures. Now, in limiting our attention to a portion only of this layer, *a b*, it will be seen that the surface *a b* is at once pressed from above, downwards, by the liquid column *c d b a*, and from below, upwards, by a precisely equal force; so that if a solid were plunged into the water whose base exactly occupied *a b*, this pressure would act upon the solid from below, upwards, tending to drive it out of the liquid.

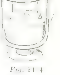

Fig. 1194.

This will be clear from the following experiment.—A tolerably large glass tube, *t*, Fig. 1195, ground flat at its lower extremity, is closed by means of a glass plate or valve, *v v*, from the centre of which proceeds a string up to the top of the tube. If the surfaces be tolerably smooth, the valve will close the tube water-tight on pulling the string. On lowering the tube thus closed into the vessel of water, A B C D, the thread can be let go, because the valve will be upheld by the upward pressure of the water; and that this pressure is equal to that which it would sustain at that depth from a column of water acting from the surface, downwards, is proved by pouring water into the tube. As soon as the interior level approaches the exterior *a a*, the glass valve is pressed from above as much as it was before pressed from below, and it then falls to the bottom of the vessel by its own weight; or rather by the difference between its weight and that of an equal bulk of water, for it cannot descend without raising such a quantity of water, just as the heavy arm of a balance cannot descend without raising the lighter arm.

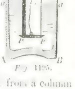

Fig. 1195.

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(1) That is, its height above the *centre of gravity* of the surface.

The pressure, then, upon a given surface, is the same, whether it face upwards or downwards; and may also be proved to be the same in whatever direction it be turned, provided its centre of gravity remain at the same depth below the liquid surface; for this pressure is equal to the weight of a column of liquid whose base is the given surface, and whose length equals the depth of its centre of gravity.

In water, the pressure on any surface at the depth of 1 foot is equal to nearly half a pound on the square inch. At 2 feet depth it is about 1 lb. At 3 feet = 1½ lb. At 4 feet = 2 lbs. At 5 feet = 2½ lbs. In a cubical vessel full of a liquid, the pressure on any one side is equal to one-half the pressure on the base; for the bottom sustains a pressure equal to the whole weight of the fluid, and the pressure sustained by each side is equal to the weight of a mass as long and broad as that surface, and as deep as its centre, and, consequently, equal to half the contents of the vessel. Hence we get the remarkable result that, in a cubical vessel, a liquid produces a total amount of pressure 3 times as great as its own weight; for if this equal 1, and the pressure upon each of the 4 sides be equal to half that upon the base, then 4 × ½ = 2 and 2 + 1= 3.

In any surface which sustains the pressure of a mass of fluid, there is a point called the *centre of pressure*, at which the whole pressure of the mass may be conceived to act, and to which, if a single sufficient force were applied, the mass of fluid would be supported, and the surface kept at rest. In any vertical surface extending to the top of the fluid, this point is at one-third the depth of the fluid from the bottom, and at the middle of the breadth of the surface. The determination of this point is of the highest importance in all works made to resist fluid pressure.

When a number of vessels communicate with each other, whatever be their form or size, the same conditions of equilibrium apply to the fluid contained in them as to a single vessel. In the first place, the surfaces of the fluid in the vessels are all *level;* and, secondly, they are all *at the same level*, provided the same fluid be used. Thus, on filling the large vessel A with water, or mercury, or any other fluid, it will exert a pressure on the side tube, near the bottom, equal to the area of the tube × by the height, × by the density of the fluid; and on opening the stopcock *c*, the pressure will cause the fluid to ascend into the small vessel B until it attains the same level as in A, when equilibrium will be established, because the water in A, as well as the water in B, presses upon the same space at *c*, and both are of the same height.

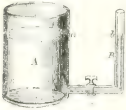

Fig. 1196.

If fluids of different densities, such as water and mercury, be made to communicate, the height to which they will rise in the limbs of a vessel such as A B, Fig. 1197, will be respectively in the inverse ratio of their densities. If the bend be first filled with mercury, and water be then poured into A, a column of that fluid, 13·6 inches high, will be necessary to balance 1 inch of mercury in B, mercury being 13$\frac{6}{10}$ times denser than water. It matters not how unequal in bore may be the two branches of the tube: if the experiment be repeated in such an apparatus as Fig. 1196, the result will be the same, whether the mercury be in A or in B; the whole height of water will always be 13·6 times that of the higher mercurial level above the lower.

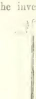

Fig. 1197.

The *densities* or *specific gravities* of different bodies are usually compared with water as a standard, on what is sometimes called the *principle of Archimedes*, namely, that when a solid is immersed in a fluid, it displaces a quantity of the fluid exactly equal to its own bulk. If the quantity of fluid thus displaced be lighter than the solid, the solid will sink in the fluid; if it be of the same weight, it will rest indifferently in any part of the fluid; if heavier, it will float in such a manner as to displace only as much fluid as may equal its own *weight*. But confining our attention to the first case (of a body that sinks), the body thus immersed in the fluid apparently loses a portion of its weight exactly equal to that of the fluid displaced, as the following experiment will prove. A solid cylinder of copper s, Fig. 1198, exactly fitting into a hollow cylinder c of the same material, are both suspended from an arm of a balance, and brought into equilibrium by weights in the opposite scale-pan P. The solid cylinder is allowed to dip into an empty glass. On filling up this glass with water, so as completely to immerse the solid cylinder, the scale-pan P will sink down in consequence of the apparent loss of weight in the cylinder s. Now, on filling up the hollow cylinder c with water, the balance is restored. The fluid support which is given to s is represented by the weight of the water in c required to restore the equilibrium of the balance; and as s exactly fits into c, the bulk of water poured into c must be exactly equal to that displaced by s. And this would be true, whatever might be the material of s, whether gold or cork. If it were cork, it would appear to lose more than its whole weight, or to acquire, when immersed, a levity or upward tendency, which, however, is still found to be neutralized, and its exact weight restored,

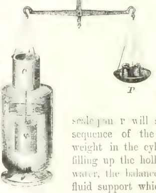

Fig. 1198.

by filling c. It is scarcely necessary to observe, that all apparent instances of a tendency the reverse of gravity, as in smoke, balloons, &c., are only effects of this kind depending on the pressure of the surrounding fluid, which must be denser than the rising body.

The method of taking the specific gravities of bodies is described under GRAVITY SPECIFIC. When a body *floats* on a fluid, it displaces a quantity equal in *weight* to itself; when it *sinks*, it displaces a quantity equal in *bulk*. Hence the conditions of equilibrium in floating bodies are two:—1st. That the portion immersed : the whole bulk : : the density of the solid : that of the fluid. 2d. That the centre of gravity of the solid, and that of the fluid displaced, are in the same vertical line. The equilibrium, however, may be stable or unstable; and if stable, the body will, on being disturbed, return to its former position by a number of oscillations which are isochronous, like those of the pendulum; and their times depend on the position of a point called the *metacentre*, which has the properties of the *point of suspension* in pendulums. When the metacentre is *lower* than the centre of gravity of the whole body, the equilibrium is *unstable;* otherwise it is stable.

The principles which regulate the motions of fluids constitute the science of *Hydrodynamics* or *Hydraulics*. This subject is one of great complexity, on account of the facility with which a fluid mass is set in motion by the disturbance of a few only of its particles; and the resulting motions are modified, either in their velocity or in their direction, by so many causes, that it is difficult to anticipate or explain the various phenomena which arise. There are, however, in this science certain fundamental laws which go far to generalize the phenomena.

The sides of a vessel containing a fluid are subject to two opposite forces—one arising from the hydrostatic pressure of the fluid, tending to burst the vessel outwards; the other, from the atmospheric pressure, or that of any other medium surrounding the vessel, tending to burst the vessel inwards. If an opening be made in the side or base of the vessel, the liquid will flow out, provided the interior pressure be greater than the exterior. In the common trick of covering a glass quite full of water with a piece of paper, and inverting the glass without spilling the water, the atmospheric pressure is greater than that of the water, and would continue to be so if the glass were 32 feet in depth. If the mouth of the glass be small, as in a narrow-necked phial, no paper need be used, for, on inverting it, the pressure of the air on the mobile but narrow surface of the fluid will prevent it from flowing out without dividing, which its cohesion prevents it from doing. If the neck be enlarged, the air, being so much lighter than the water, will force a passage up through it, and break up the liquid column. But if an opening be made in the top of the vessel, the liquid will flow smoothly, as if no air were present; for the atmospheric pressure, together with that of the fluid *within,* is opposed to the atmospheric pressure alone *without;* and the motion is produced by the difference of these pressures, viz. that of the liquid alone.

In the examples which we are about to consider of liquids escaping from an orifice, the flow will result from excess of pressure, and not from the breaking up of the liquid column. But, in order that results may be comparable, it is necessary that the surface of the liquid in the containing vessel be maintained at the same height by some contrivance which shall add to the vessel the same amount of liquid as flows from it. In such case, neglecting all mechanical obstacles arising from friction and other causes, the flow of liquids from orifices in vessels obeys the force of gravitation, and their motion becomes accelerated, according to the law of falling bodies. The expression of this law, known as *Torricelli's theorem,* is, That particles of fluid, on escaping from an orifice, possess the same velocity as if they had fallen freely *in vacuo* from a height equal to that of the fluid surface above the centre of the orifice.

All bodies falling from the same height *in vacuo,* acquire the same velocity; but the flow of liquids from an orifice does not depend upon their densities, but only on the depth of the orifice below the level of the fluid. Mercury and water, for example, flow with the same velocity when they escape by similar orifices at the same depth below their levels; for although the pressure of the mercury is 13½ times greater than that of the water, it has 13½ times as much matter to move.

The velocities acquired by falling bodies are as the square roots of the heights; so that in order to produce a twofold velocity, a fourfold height is necessary, &c.; so also in the escape of liquids from an orifice, the velocities are as the square roots of the depths of the orifices below the surface of the fluid; so that, if we wish to double the velocity of discharge from the same orifice, a fourfold depth is required; to obtain a threefold velocity, a ninefold pressure is necessary, and so on. Because, in an equal time, *thrice* as much matter has to be moved with *thrice* as much velocity.

When a vessel with vertical sides is allowed to empty itself by an orifice in the bottom, the quantities flowing out in successive equal intervals are as a diminishing series of odd numbers (as 9, 7, 5, 3, 1), or as the spaces described in equal intervals by a falling body, *taken backwards.*

In such cases there forms, after a certain time, a hollow depression on the surface immediately over the orifice: this increases until it becomes a cone or funnel, the centre or lowest point of which is in the orifice, and the liquid flows in lines directed towards this centre.[1] Of course, the issuing stream or vein is vertical if the orifice is at the bottom of the vessel, or it describes a parabolic curve if the orifice is at the side. In either case it moulds itself, as it were, to the form of the orifice, and extends to a considerable distance before it scatters and divides into drops. Between the mouth of the orifice and the point where it begins to divide, the liquid vein has a permanent form, and a polished surface; and notwithstanding the rapid motion of the liquid particles which succeed each other incessantly, the jet has the appearance of a perfectly motionless rod of glass. At the commencement of its course, the vein is of the same diameter as the orifice, but for a short distance its diameter grows less, forming what is called the *vena contracta*, or contracted vein of fluid, Fig. 1199. The reason for this contraction appears to be, that as the liquid particles approach the orifice, they converge to a point beyond it, so that the liquid column in escaping must necessarily be narrower or more contracted at the point towards which the motion of the liquid converges, than it is either before it arrives at that point, or after it has passed it. The greatest contraction of this fluid vein is at a distance from the orifice equal to half its diameter; the diameter of the contracted portion being to that of the orifice as 5 : 7.

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[1] In th[illegible] the liquid a rotary motion is imparted to it, and [illegible] as all the particles are approaching the centre [illegible] by virtue of their inertia they tend to maintain the same velocity which they had in a larger circle, so that their angular velocity (or the number of revolutions in a given time) is constantly increased.

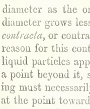

Fig. 1199.

Hence the real discharge of fluid is only $\frac{25}{49}$, or about half of the theoretic discharge, or that which would take place if the whole orifice transmitted fluid with the velocity of a body that had fallen from the surface. It is evident that only those particles which are vertically above the centre of the orifice can descend through it in a straight line. All others coming from the sides of the vessel must move in lines more or less inclined. Hence the particles on the outside of the effluent stream are retarded, and move more slowly than those in its centre. Hence also arises the difference between the *mean velocity* of the escape and the velocity due to gravity.

The division of the vein at a certain distance from the orifice is not produced only by the presence of the air; it takes place *in vacuo*, and is the result of the acceleration due to gravity. The effect of this acceleration is best seen in a stream of treacle, which tapers downwards, because the flow, or quantity passing in a given time, must be equal at all points of the stream, so that wherever the *velocity* is greater than at another point, the size, or *sectional area*, of the stream must be diminished in the same proportion. In water, however, the cohesion is not of such a kind as to admit of this tapering; but each portion, when it has acquired a certain velocity, tears itself away from the stream, forming a drop, and leaving the stream, which has been forcibly elongated, to contract again, till another drop is detached. Thus each drop is subject during its fall to certain periodic vibrations, by which it alternately elongates and contracts. A series of pulsations, also, occurs at the orifice, the number of which is in the direct ratio of the rapidity of the current, and in the inverse ratio of the diameter of the orifice; they are often sufficiently rapid to produce a distinct musical sound. If a note in unison with this be played on a musical instrument at such a distance as to be scarcely audible, the aërial pulses thus produced have a marked effect on the vein in shortening the limpid part.

When a tube is added to the orifice, the flow is accelerated if air be present, but, *in vacuo*, no such acceleration takes place. The most remarkable and useful result, however, of the experiments on the flow of water through pipes, is the discovery that it may be accelerated by merely giving particular forms to the commencement and termination of the pipe, without altering its general capacity. A 4-inch pipe, of any length, may be made to deliver considerably more water, if its first 3 inches and last yard be enlarged conically, than if they were cylindrical like the rest of the pipe.

One of the most intricate subjects to which the laws of motion have yet been applied deductively, is that of *liquid waves*. When any portion of a liquid surface is raised above or depressed below the rest, we have already seen, Fig. 1191, that it will return to the general level, but in so doing it acquires a velocity which necessarily carries it beyond the position of equilibrium, and thus produces a series of oscillations, which are communicated in every direction over the liquid surface, each portion receiving its motion from that preceding it, and therefore arriving at each phase of its oscillation a little later than the preceding portion; whence arises the appearance of a form travelling along the surface, which form we call a *wave*. Each wave contains, at any one moment, particles in all possible stages of their oscillation, some rising, some falling, some at the top of their range, some at the bottom; and the distance from any row of particles to the next row that are in precisely the same stage of their oscillation, is called the *breadth of a wave*. Now as these oscillations are caused by the force of gravity, we may expect some analogy between their laws and those of the pendulum; and accordingly, when the depth of the liquid is disregarded, or considered as unlimited, the wave-breadth (like the pendulum-length) varies as the square of the time of oscillation; so that the time which elapses between the arrival of the crests of two successive waves at a fixed point, is as the square root of the distance between them, or the distance which either of them travels over in the said time; hence it is easy to see that their velocity varies inversely as the square root of their breadth. For instance, if a certain buoy be observed to rise and fall twice as often as another, the waves which pass it must be four times as broad as those which pass the other, but as they travel over this *quadruple* distance in only *double* the time, they must evidently move with a double velocity.[1] When the water, however, is so

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(1) The velocity of waves that run in the same or the opposite direction with a ship, may be ascertained by means of the log, or any other floating body, attached to a known length of cord. By noticing the time that elapses between the hitting of this body, and that of the ship's stern, by the same wave, and adding or subtracting the way made by the ship during that interval, we find the

shallow that the waves are affected by the form of the bottom, the simplicity of these results gives place to an extreme degree of complexity. The use of these investigations lies in their application to the *tides*, which may be regarded as waves of moderate height, but enormous breadth and velocity, the time of oscillation being half a lunar day, and the velocity sometimes 1,000 miles an hour.

To Hydrodynamics belongs, also, the theory of such machines for raising water as do not depend on atmospheric pressure. Such are the *water-screw*, invented by Archimedes, the endless *chain of buckets*, the *water-ram*, the *hydraulic belt*, &c. This last-named machine, the use of which has been revived within a few years, is one of the most efficient of water elevators, yet the most inexplicable in its action. In its ancient form it consisted of a number of hair-ropes, for which a band of flannel, or felt, is now substituted, passing over two rollers, one at the top, and the other at the bottom of the well. By means of the upper roller, it is set in very rapid motion, when the water adheres to its surface in a layer which is thicker the more rapidly it moves, and becomes nearly half an inch thick when the velocity is 1,000 feet per minute. It follows the band to any height, and is thrown off by centrifugal force, in turning over the upper roller.

To this science also belongs the application of the power of streams and waterfalls to useful purposes. The chief means of effecting this, are, the *undershot* wheel, the *overshot* wheel, the *breast* wheel, the *horizontal* water-wheel, the *hydraulic engine*, *Barker's mill*, and the *Turbine*. The first two are too well known to require a description, but we may observe, that the overshot wheel is always the most advantageous where the height of the fall is sufficient to admit of its use. The smallest rill may be applied in this manner, but the undershot wheel requires a considerable body of water. The breast wheel unites, in some measure, the advantages of both, and is applicable to falls of a medium height, as it requires only a fall equal to its *radius*, and not to its *diameter*, as is the case with the overshot wheel. This wheel is formed with plain floats, but the water enters at the level of its axle, and descends round one quadrant of its circumference, which is enclosed for this purpose in a sort of box of masonry. The horizontal water-wheel is used in some parts of France, and is the most applicable to a small fall, and a small quantity of water. Its floats are set diagonally, and may receive the water at one or at several points of its circumference at once. In the hydraulic engine, the pressure of a column of water is applied as the motive power, by means of a piston and cylinder, like those of the steam-engine. The Turbine, which acts on a similar principle to that of Barker's mill, may be described as a water-wheel with a vertical axis; it has hitherto been principally used in France, where it has been brought to great perfection. It is, perhaps, the least wasteful of all modes of applying the power of a waterfall. It will be described more particularly further on.

In all water-wheels it is a constant rule that the greatest mechanical effect will be produced when the velocity of the parts driven is just *half* that of the stream driving them; and this is a most important principle, applicable also to the sails of windmills and ships, and the paddles of steamers. It is obvious that the pressure of the wind or water on any of these bodies diminishes as their velocity approaches that of the current, so that if it were possible for a water-wheel to revolve with exactly the velocity of the stream, there would be no pressure on its floats, and consequently, no power to drive any other machinery. On the other hand, the pressure is at a maximum when the wheel is standing still, but then having no velocity, it is also powerless. As the power then is proportional to the *product* of the pressure and velocity, it is greatest when they have each their mean value, that is, in the exact medium between these two states,—*rest* and *motion with the current*,—in other words, it is greatest when the velocity is *half* that of the current.

We will conclude this concise statement of the principles of Hydrostatics and Hydraulics, (for which the Editor is indebted to his small work on Mechanics, published in Weale's Rudimentary Series,) with a detailed description of those very important machines, the *hydrostatic press* and the *hydraulic ram*.

HYDROSTATIC OR HYDRAULIC PRESS.—Although a machine of this kind was proposed by Pascal in 1664, it was not till 1796 that Bramah succeeded in overcoming certain difficulties in its construction, which will be explained presently. One form of the press is represented in Fig. 1200, the working parts of which are shown in section in Fig. 1201: C is a massive cylinder, in which the solid piston or plunger P moves up and down, carrying at the top a plate A, between which and the top of the press B, the goods or substances F intended to be pressed are

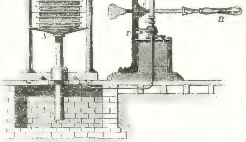

Fig. 1200.

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time which the wave takes to travel the length of the cord. In this way it has been found, that in the open ocean, some waves travel at the rate of 50 miles an hour, the breadth of such waves is sometimes a quarter of a mile. The utmost difference of level is found by measuring how high above the ship's water line an eye must be raised to have an uninterrupted view of the horizon. No authentic observation of this kind gives more than 25 feet, even in the greatest storms.

placed. Water is forced into the cylinder C by means of a pump P, of which the long piston *r* is worked by a lever upon a point *c*, and terminating in a handle H, the piston *r* being further guided in its vertical motion by a ring at *e*, in which the stem of the piston *r* works. At each up stroke of the piston, water is drawn up from a reservoir placed beneath the pump, and at each down-stroke, it is forced along the tube T into the cylinder C. A valve *v* opening upwards allows water to pass up from the reservoir, but not to return back again; and another valve V′ opens to allow the water passage along T into C, but closes against its motion in the contrary direction.

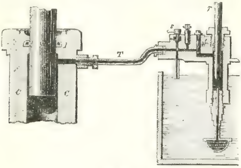


Fig. 1201.

Now it is evident from what has been already said, that the power of this machine depends partly on the proportion of the magnitudes of the two pistons, and partly on the leverage of the arm *c* H. Suppose the diameter of the cylinder to be 12 inches, and that of the piston of the small pump or injector only $\frac{1}{4}$ of an inch, then the proportions between the two surfaces or ends of the pistons, will be as 1 to 2,304, so that a force applied to the small piston will be multiplied 2,304 times. If the small piston or injector be forced down with a pressure equal to 20 cwt., the piston of the great cylinder will act with a force equal to $20 \times 2{,}304 = 46{,}080$ cwt. $= 2{,}304$ tons, which enormous power may be applied either in drawing or pressing in much less time than the same could be produced by any other means.

Now the difficulty in constructing this press before the time of Bramah, arose from the leakage of water from the cylinder C, which, of course, rendered the press useless. Bramah overcame this difficulty by constructing a leathern collar L in such a way, that the very tendency of the water to escape, only caused such collar to fit the more tightly in its place. To make this collar, a circular disc of leather is first cut out; and from this a second disc is removed, so as to leave a broad flat ring. This is softened by steeping in a liquid, and then bent and moulded into a collar of the form shown in section, Fig. 1202, in which condition it is fitted into a circular cavity L, Fig. 1201, made for the purpose in the cylinder C. The plunger P is then put into its place, and it moves up and down with friction against the interior bend of the collar. Now it is evident that when the water is forced into C, it will insinuate itself into the hollow concavity of the collar, and being under an enormous pressure, will press the collar tightly into its place, and thus form a perfectly tight joint.

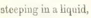


Fig. 1202.

The power of this press is only limited by the strength of the cylinder C. We have already seen, that in raising one of the tubes of the Britannia Tubular Bridge, the cylinder of one of the enormous hydrostatic presses used for the purpose, gave way. [See BRIDGE, vol. i. p. 248.] It is usual, however, in order to prevent such an accident, to furnish the press with a safety-valve, consisting of a conical plug pressed down by a weighted lever, as shown in Fig. 1203. The size of the weight W, and its distance from the fulcrum are determined, so that the valve shall not yield to the pressure of the liquid, until such pressure exceed a certain limit, at which it is desired to work.

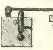


Fig. 1203.

The action of the press can be suspended in a moment by means of the screw *s*, Fig. 1201, the lower part of which plugs up a channel leading into the supply cistern. On turning this screw one way, the water cannot escape, and the water raised by working the pump-handle H, Fig. 1200, is employed as power to raise the plunger P; but on turning the screw the other way, the water flows back into the cistern, the pressure in C is instantly relieved, and P descends.

A press patented a few years ago by Mr. Wilson, exhibits a marked novelty in being constructed with two concentric rams. These are acted upon alike by the water, but from the difference of the areas of the two, the large or outer ram always tends to rise first, carrying of course the smaller ram with it. Such a form of press tends much to economise labour in working substances which may be pressed in a case or cylinder. The arrangement of parts and mode of working, will be best understood by the following description. The two rams A, B, Fig. 1204, are exposed to the same working pressure, there being a hole left in the large ram A, to admit the water to the small interior ram. The check rod C, serves to stop the large ram whenever it has risen to a certain height, while strong bolts fixed on the top of the water cylinder (but not shown in the figure) are placed so as (when pushed in) to prevent the large ram from rising at all. Leathers of the usual form are applied to form water-tight joints around this check rod, and also around both rams. The oil cylinder D D is of stout cast-iron, and is pierced with holes to allow the escape of the oil from the substance submitted to pressure within it. The top or head of the press E is movable, and is, when in its place, kept down by the dogs or hinged catches *f f*, forming the ends of the press bars F F. The mode of using this press is as follows:—The top E, being lifted off by means of a chain and winch, and the pumps set to work, the large ram rises as far as the check rod will allow it, and then the small ram rises alone to near the top of the oil cylinder. The water is then allowed to escape slowly, and as the small ram first, and then the two rams together, sink, the charge is filled into the cylinder D D, in the usual portions, divided by iron plates, and mats, or baskets. When the charge is complete, the top is put on, and the large ram being held down by the bolts, a light pressure is given by the small ram, to compress and consolidate the loose charge.

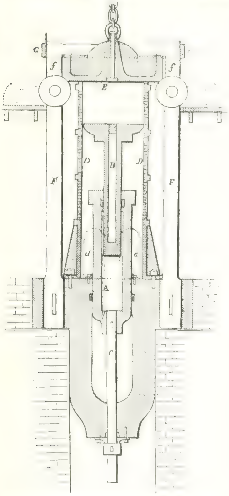


Fig. 1204. SECTION OF DOUBLE HYDROSTATIC PRESS.

The head is again removed, and as the water is allowed to escape slowly and the ram to fall, the space left in consequence of this compression is filled or "topped up" by additional charge. Then all being ready, the head is again put on and secured by the dogs, which are prevented from springing back by the ring G G, wedged up behind them, the large ram is released and the full pressure applied and maintained as long as necessary. When this is completed, the pressure is slackened, so as to permit the removal of the head, and the pumps are again put to work, so as to raise at first the two rams, and then the small one alone, and thus lift the spent charge out of the oil cylinder. Then the same process of charging, topping up, and finishing, is gone over again as at first. The advantage in this press arises from the capability of operating upon a large quantity of material in a long cylinder of small area, and therefore under a great pressure, while from the use of the two rams as described, the loose charge is rapidly consolidated by a first pressure quickly applied, and the spent charge, which from the small area of the oil cylinder could not be dug out, is readily lifted out by a slow motion, which allows of its easy removal. For hot-pressing, the oil-cylinder may either be surrounded by a steam-jacket of iron plate, or the entire press may be built into a hot room, leaving only the top of the oil-cylinder open to the charging floor above. The oil which flows down the sides of the oil-cylinder, is collected in a tray placed beneath it, and conducted by a shoot or pipe into the proper vessel or reservoir. The bolts are placed in openings *d d* at the bottom of the oil-cylinder, which openings serve also to give access, when needed, to the leathers of the two rams. For some purposes, the large ram might be left without any hole for the admission of the water to its interior, from the water-cylinder, and a pipe, sliding in a water-tight collar, might be made to convey the water directly from the pumps to the interior of the large ram. This, then, becomes a cylinder to the small ram, and the check rod and bolts may be dispensed with, as the water may be made to act on either of the rams alone, by the adjustment of the cocks in the supply pipes. Care must obviously be taken in all cases, not to apply too great a pressure to the small ram when rising alone, for fear of breaking the bolts or check rod of the large ram, or when separate pipes are used, for fear of bursting the large ram, if it is at all raised out of the cylinder.

THE WATER RAM, or *Belier Hydraulique*, invented by Montgolfier, and improved by his son, is one of the most simple and beautiful of hydraulic machines. Its object is to raise water without the aid of any other force than that produced by the momentum or moving force of a part of the water that is to be raised; and the effect is so great, that the machine appears to act in opposition to the laws of hydrostatic equilibrium, for a moving column of water of small height is made to overcome and move another column much higher than itself.

The construction and action of the water-ram will be understood from the accompanying steel engraving, in which H is a head of water discharging itself into a pipe B, along which it flows with a velocity depending on the height of the fall, and it escapes to waste unless prevented at the orifice C, which admits of being opened or shut by a valve. F is a reservoir of air, which is connected with the conduit tube B D by a small cylinder *a b c d*. In the bottom of F is a circular orifice, to which a small cylindrical support is adapted, of which the extremity E is furnished with a valve. F is supplied with air by a valve *s*, and there is also a space, *m n*, full of air. G A is an ascent tube, rising into a cistern at the top of the house, or to any considerable elevation where a supply of water is required. The pipe B D, through which the water runs, is called the ***body of the ram***; the pipe G H, the *tube of ascension*; C is the *stopping* *valve;* and E the *ascension valve.* These valves are hollow globes weighing about double the weight of water which they displace, and over each is a metal bridle to prevent it from rising too high. The extremity of the body C, and the reservoir E, form what is called the *head of the ram.*

The action of the ram is as follows:—The water escaping through C with a velocity due to the height of the fall, forces the ball D out of its muzzle, and raises it to the orifice C, which it immediately stops. The water thus suddenly arrested in its passage, would, by its momentum, burst the tube, were it not for the other valve e, which is lifted up, and allows the water to escape into the reservoir F, whereby the air is compressed, and by its spring, forces water up the tube A, just as water is forced out of the jet by the elasticity of the air in the air-chamber of a fire-engine. [See FIRES, vol. i. p. 662.] The ball e soon loses the velocity imparted to it by the stopping of the orifice C, and descends by its own weight, as does also the ball D, into their first positions; the water then runs off again at C, until its velocity is sufficient to raise the ball D, when the orifice is again closed, and E again opened by the reaction, and thus the effects are constantly repeated, in times which are sensibly equal, in the same ram, and with the same current.

In the action of this machine, four distinct periods may be traced: 1, the water-escapes through the orifice C, with a velocity due to the fall, and that orifice is closed; 2, the air in the space $m\ n$ is compressed; 3, the ascension-valve is opened, the air in the reservoir compressed, the water rises in the ascension-tube G, the ascension-valve e is shut, as is also the valve D; 4, the air compressed in the second interval reacts, the valve D descends from the orifice, and the water, again acquiring its velocity, again produces the like effects.

It will be seen from these details, that a very insignificant pressing column $h\ h'$ is capable of raising a very high ascending column G A, so that a sufficient fall of water may be obtained in any running brook by damming up its upper end to produce the reservoir H, and carrying the pipes B D down the channel of the stream until a sufficient fall is obtained. A considerable length of descending pipe is desirable to ensure the action of the machine, otherwise the water, instead of entering the air-vessel, may be thrown back into the reservoir. Air is admitted from time to time into the annular space $m\ n$, whence it finds its way into F.

To estimate the value of this or, indeed, of any hydraulic engine, its produce must be ascertained, the expense of its erection, and that of keeping it in repair. In every hydraulic engine, the force expended is the product of the water as it comes from its source, multiplied by the height through which it falls before it acts on the machine; the produce being the quantity of water raised in the same time, multiplied by the height to which it is elevated.

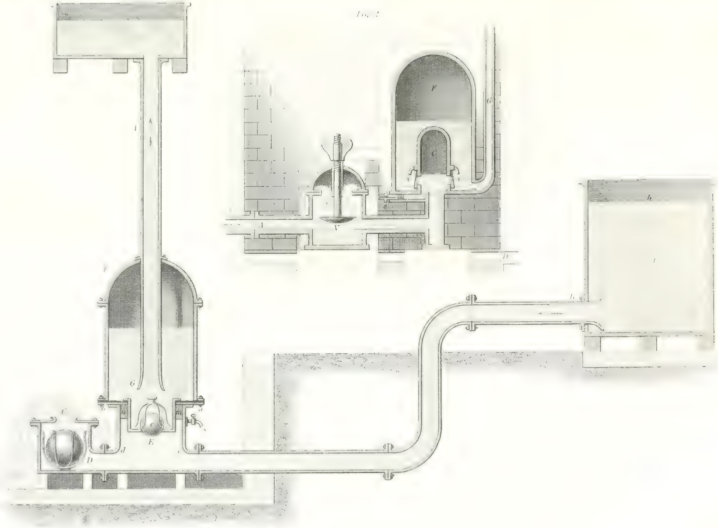
In a ram placed by Montgolfier in his garden, the fall, which was procured artificially, was $7\frac{1}{2}$ feet. The height to which the water was raised, 50 feet; the diameter of the tubes 2 inches; the water expended in 4 minutes, was 315 litres, that elevated 30 litres; hence the expense of force employed is $7\frac{1}{2} \times 315 = 2{,}362$; the useful force $50 \times 30 = 1{,}500$, which give the ratio of 100 to 64 as the expense to the produce. It appears, however, from the mean of a number of experiments, that the expense will be to the produce as 100: 57, so that a hydraulic ram executed with care, and placed in not unfavourable circumstances, employs usefully, at least, half its force.

The younger Montgolfier so far improved upon this machine, as to make the work performed amount to about 60 per cent. The alterations introduced by him, are shown in the second figure of the steel engraving, in which A is the feed-pipe or body of the ram; V the stoppage-valve suspended by a stem to a sort of stirrup; F the air reservoir, enclosing a smaller reservoir C, called the *air-matrass;* $v\ v'$ are the ascension-valves, and G the tube of ascension. The action is as follows:—The water in A flowing in the direction of the arrow, soon acquires sufficient velocity to close the valve V, and to open the valves $v\ v'$, whereby a certain quantity of water enters F, and passes up G. This impulse or momentum being expended, the valve V descends, the water overflows, and is carried off by a pipe D; after which the same phenomena are repeated. Now it will be seen, that as soon as the water rises above the valves $v\ v'$, air is imprisoned in the matrass C, and when the force of the water after shutting V comes to expend itself upon the air-vessel F, the violence of the shock, which is considerable in the arrangement shown in the first figure, is in this case greatly lessened by the interposition of C, which acts as a sort of air-cushion; it also causes the valves to shut with less noise, and prevents the pipe from undergoing such violent strains. In short, while a much larger amount of work is done, all the operations take place with so much ease, that the machine is less shaken and put out of repair than in the former apparatus. When the force which opens the valves $v\ v'$, and compresses the air in C is expended, this air expands, and in doing so, assists the retrograde motion of the water in the pipe. The air in C, in expanding, has for a moment a less pressure than the external air, a circumstance which is turned to useful account in keeping both C and F supplied with air, as will be noticed presently. The valves $v\ v'$ remain open so long as the opening pressure exceeds that which is exerted upon them by the fluids in F. The air-vessel F also derives advantage from the matrass C, for as soon as the valves $v\ v'$ are opened, and water enters, compressing the air in F, the water is not immediately forced up the tube G, but can accumulate somewhat in F, and thus act with great effect, for it is evident that the pressure required to open the ascension-valves, would be much greater if the whole column of water G passed suddenly from a state of rest into one of motion at the moment the valves were opened, and they would in such case also remain open a much shorter time.

One of the great defects of the fire-engine, is the

Fig. 1

Fig. 2



absorption of the air in the air-chamber by the water, which takes place all the more rapidly as the pressure is great. Now the air in F becomes dissolved rapidly in proportion to the increasing elevation of water in the ascension-tube: wherefore in order to keep up a constant supply, a small snifting-valve is added at H, consisting merely of a tube with a fine capillary bore left entirely open. At the moment when the water of the ram is relieved from pressure, the density of the air in C becomes slightly less than that of the outer air, as already noticed; consequently a small portion of air rushes in through the valve with a noise like the *sniffling* of a person's nose, whence this kind of valve is called a *snifting*-valve. A portion of the air thus admitted finds its way through the valve v v' into F, to supply the place of that which is dissolved, and carried off by the ascending-column. At every blow of the ram, *i. e.* every time the valve B is closed, and the water is under compression, a small jet of water is darted out of the snifting-valve; this valve therefore acts as a sort of pulse to the machine, drawing in air and jetting out water by regular periodical movements. Indeed the pulsatory motion of the ram becomes painfully evident where the column to be raised is considerable. In such case, the ground over the pipe is shaken at every blow, and a tremor is felt in every room of the house against the wall of which the supply-pipe ascends. By covering this pipe with felt, the evil may be to a certain extent mitigated, but cannot be entirely overcome. Indeed this is the great objection to this otherwise admirable engine.

In the Exhibition of 1851 a hydraulic ram was exhibited in action by Messrs. Easton & Amos. They had also one in action in the yard of their premises in Castle Street, Trafalgar Square. They state in their circular, that they have erected upwards of 500 of these machines in different parts of Great Britain and Ireland. Persons who have small running streams on their estates, and require water to be raised to the tops of their houses, can do so at very moderate cost. These self-acting water-rams will raise water 30 times the height of the waterfall by which they are worked. In giving estimates, the makers require to know:—1. The number of feet fall that can be obtained at the spring or brook to work the ram. 2. The perpendicular height from the lower part of the fall to where the water is required to be delivered. 3. The distance horizontally from the spring or brook to the house or premises where the water is wanted. If the spring or stream should be small, it is desirable to ascertain how many gallons flow per minute.

The *Turbine*, or *horizontal water-wheel*, is practically unknown in Great Britain, although in extensive use in France and Germany, and its working results are so extraordinary, that some account of it may be of use in this place.

In order to understand the principle of the turbine, we must refer more particularly to Dr. Barker's mill, shown in plan and elevation, Figs. 1205, 1206. It consists of an upright pipe or tube, with a funnel-shaped open top but closed at the lower end, from which project two horizontal pipes or arms, closed at the outer ends and placed opposite to each other at right angles with the vertical tube. Near the end of each horizontal pipe, and on one side of it, is a round hole, the two holes being opposite to each other. The upright pipe is mounted upon an axis or spindle, and is kept full of water, which flows into the top. The water issuing from the holes on opposite sides of the horizontal arms, causes the machine to revolve rapidly on its axis, with a velocity nearly equal to that of the affluent water, and with a force proportionate to the hydrostatic pressure given by the vertical column, and to the area of the apertures: for there is no solid surface at the hole on which the lateral pressure can be exerted, while it acts with its full force on the opposite side of the arm. This unbalanced pressure is, according to Robison, equal to the weight of a column, having the orifice for its base, and twice the depth under the surface of the water in the trunk for its height. This measure of the height may appear extraordinary, because if the orifice were shut, the pressure on it is the weight of a column reaching from the surface. But when it is open, the water issues with nearly the velocity acquired by falling from the surface, and the quantity of motion produced, is that of a column of twice this length moving with this velocity. This is actually produced by the pressure of the fluid, and must therefore be accompanied by an equal reaction. When the machine, constructed as in Fig. 1206, moves round, the water which issues descends in the vertical trunk, and then moving along the horizontal arms partakes of the circular motion. This excites a centrifugal force, which is exerted against the ends of the arms by the intervention of the fluid. The whole fluid is subjected to this pressure, increasing for every section across the arm in the proportion of its distance from the axis; and every particle is pressed with the accumulated centrifugal forces of all the sections that are nearer to the axis: every section, therefore, sustains an actual pressure proportional to the square of its distance from the axis. This increases the velocity of efflux, and this increases the velocity of revolution; which mutual co-operation would seem to terminate in an infinite velocity of both motions. But on the other hand, this circular motion must be given anew to every particle of water as it enters the horizontal

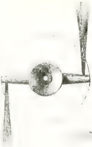


Fig. 1205

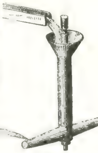


Fig. 1206

arm. This can only be done by the motion already in the arm, and at its expense. Thus there must be a velocity which cannot be overpassed, even by an unloaded machine. But it is also plain, that by making the horizontal arms very capacious, the motion of the water to the jet may be made very slow, and much of this diminution of circular motion prevented.

Desaguliers, Euler, John Bernoulli, and De la Cour, have treated of this machine, and a few years ago Mr. James Whitelaw, of Paisley, took out a patent for improvements in it; but the turbine, as used in France, appears to be the invention of M. Fourneyron, and its value consists in its applicability to falls of water so high or so low that an ordinary water-wheel cannot be used; and in falls of great height it requires little or no mill work to produce the requisite speed.

The turbine in its present form consists of a horizontal water-wheel, in the centre of which the water enters; diverging from the centre in every direction, it enters a number of buckets at once, and escapes at the circumference or external periphery of the wheel. The water acts on the buckets of the revolving-wheel, with a pressure proportional to the vertical column or height of the fall: and it is led or directed into these buckets by stationary guide curves, placed upon and secured to a fixed platform within the circle of the revolving part of the machine. The efflux of the water is regulated by a hollow cylindrical sluice, to which a number of stops acting simultaneously between the guide curves, are fixed. With this short cylinder or hoop they are all raised or lowered together, by means of screws communicating with a regulator or governor, so that the opening of the sluice and stops may be increased or diminished in proportion as the velocity of the wheel may require to be accelerated or retarded. This cylindrical sluice alone might serve to regulate the efflux of the water, but the stops serve to steady and support the guide curves, and prevent tremor.

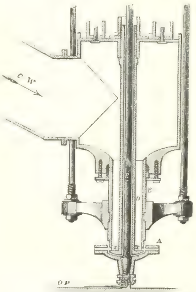


Fig. 1207. SECTIONAL ELEVATION OF TURBINE

Fig. 1207 is a section of the turbine, erected in 1837 at St. Blasier, in the Black Forest of Baden, and Fig. 1208 a quadrant of the same. The body of the machine is of cast-iron; the water-wheel or revolving part, is of hammered iron, and the spindle or axis E, of steel; B is the cylindrical sluice or regulator; *w w* the stops; C the fixed platform; *x x* the leading or guide curves which conduct and direct the water into the buckets *y y;* D is the hollow shaft supporting the platform C. The axis of the water-wheel E makes from 2,200 to 2,300 revolutions per minute, and drives the machinery of a cotton mill. The arrow shows the direction of rotation. The foot of the spindle, and the pivot and step on which it revolves, are tempered to extreme hardness. The oil pipe at the foot of the pivot is connected with a small force-pump or syringe, which, at regular intervals, injects a little oil into the step for lubrication; the pump is worked by a slow motion from the machinery. The foot of the spindle must be made hollow, and run upon a fixed pivot. The spindle must never run in a hollow step. The pivot should be quite cylindrical, and should truly fit the spindle with as little play as possible; the top of the pivot should be but slightly convex. Water and mud must be carefully excluded, and the parts regularly oiled.

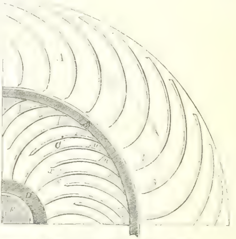


Fig. 1208. QUADRANT OF TURBINE.—*Plan.*

This turbine is moved by a fall or column of water of 72 feet. The wheel is of cast-iron, with wrought-iron buckets; it is about 20 inches in diameter, and weighs about 105 lbs.; it is said to be equal to 56 horses' power, and to give a useful effect equal to 70 or 75 per cent. of the water power employed. It is used for driving a spinning mill. A second turbine at the same mill is worked by a column of water 354 feet high, which is brought into the machine by cast-iron pipes of $16\frac{1}{2}$ inches diameter. The diameter of the water-wheel is about 13 inches, and is said to expend a cubic foot of water per second, or probably more. The width of the water-wheel across the face is less than $\frac{1}{4}$ inch. It makes from 2,200 to 2,300 revolutions per minute, and on the end of the spindle or upright shaft of the turbine, is a bevelled pinion of 19 teeth working into 2 wheels on the right and left, each of which has 300 teeth; these give motion to the machinery of the factory, and drive 8,000 water spindles, with roving frames, carding engines, cleansers, and other accessories. The useful effect is reported to be from 80 to 85 per cent. of the theoretical water power. The water is filtered at the reservoir before it enters the conduit pipes, since the apertures of discharge in the water-wheel are so small as to be easily obstructed. The water enters the buckets in the direction of the tangent to the last element of the guide curves, which is a tangent to the first element of the curved buckets. The water ought to press steadily against the curved buckets, entering them without shock or impulse, and quitting them without velocity, in order to obtain the greatest useful effect; otherwise a portion of the power of the water must be wasted or expended without producing useful effect on the wheel.

The general application of the steam-engine as the moving power for machinery, has to a great extent superseded the use of water power in England. But there are many places, especially in hilly districts, where high falls of water occur, or where reservoirs could easily be made, so as to ensure a constant supply, and where the height of the column may compensate for the smallness of its volume. In such situations the high pressure turbine, or that with a lofty column of water, may be applied with advantage for grinding corn, working threshing machines, crushing ore, &c. In other situations, where a great volume of water rolls with but little fall, with a head of only 9 inches, the low-pressure turbine has done good service.

In places where coal is scarce, but water abundant, there is another engine which may, with advantage, take the place of the steam-engine. This is the Reciprocating *Water-pressure Engine*, a description of which will be found under WATER ENGINE; to which we must refer, as also to the APPENDIX, in which will be given some other interesting applications of water power.[1]

HYGROMETER. See EVAPORATION.

HYPOCAUST. See WARMING AND VENTILATION.

ICE. The command of a proper supply of ice or snow for cooling water or other liquids in summer has long been regarded as one of the necessaries of life. And so ancient is the practice, that we even find allusions to it in the Proverbs of Solomon;—"As the cold of snow in the time of harvest, so is a faithful messenger to them that send him; for he refresheth the soul of his masters." xxv. 13.

Referring to other authorities[2] for antiquarian notices on the art of cooling summer drinks and sweetmeats, we propose to give a slight sketch of the modern method of collecting and storing up ice and snow, so as to afford a constant supply for summer; *secondly*, to state the modes which have been adopted for forming ice artifically; and *thirdly*, the methods of obtaining low temperatures by the use of what are called *freezing mixtures*.

The most simple and obvious method of securing a magazine of cold to meet the physical wants of summer, is to collect, during the winter, a store of ice or of snow, and to place it under such circumstances that it shall be shielded from rain, from warm air, and from the direct rays of the sun.

In our article on the preservation of FOOD, we stated how desirable an appendage to markets, &c., would be an ice-house, for the purpose of preserving fish, meat, fruit, and vegetables fresh much longer than can be done by other means. The simplest method of keeping ice is by enveloping it in a large quantity of loose straw. For this purpose, the ground is formed into a flattened cone, for draining off the water from any portion of the melted ice; a layer of faggots is then put therein, with straw a foot or more in thickness, and on this the ice is piled in a large conical mass, and covered with straw to the thickness of one foot, then with faggot-wood to the thickness of two feet, for the purpose of preserving a stratum of air above and around the ice; and lastly, the whole is covered with two or three feet of straw arranged as a thatch. The ice, thus surrounded with badly conducting materials, may be kept throughout the year. Some recommend as the best situation for such an ice-stack, the shade of trees, or under a shed roof, closed on the south side, and open on the north. Others consider the vicinity of trees to be objectionable, in consequence of their tendency to increase or prolong the humidity of the air. So, also, others recommend an eastern or south-eastern aspect in preference to a northern aspect for the ice-house door, in order that the morning sun may dissipate moisture from it.

An underground ice-house may consist of a large cellar, with the walls, floor, roof, and doors hollow, or double, and with a trapped drain to allow water to escape without admitting the air. Such ice-houses are usually in the shape of an inverted cone, which allows the ice to form into compact masses, in which condition it retains the solid form far better than when it is loosely piled, and should any of the ice thaw out, the slipping down of the remainder will tend to keep the mass together. But the construction of such an ice-house as this, is very costly; and according to

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(1) The above notice of the Turbine, is from a report made by Joseph Glynn, F.R.S. &c. to the British Association for the Advancement of Science. Fourneyron's Turbine has been improved and varied by M. Cadiat, by M. Fontaine of Chartres, by M. Jonval, and by M. M. Koechlin of Mulhausen. These are described in Delaunay's beautiful little work, entitled, "Cours Elementaire de Mecanique," Paris, 1851.

(2) The various methods of cooling liquors as practised by the nations of antiquity and traced to comparatively modern times are given by Beckmann in an amusing paper in his History of Inventions. See also Professor Leslie's Treatise on Cold, published in the Encyclopædia Britannica.

Loudon,[1] is not necessary, for "a plain square room with double side walls, say a foot apart, a double arch over, and a double floor under, which can be built with the same ease as any common cellar, will, all other circumstances being alike favourable, keep the ice as long as any conical form whatever." It is desirable to interpose a layer of straw, reeds, or chaff between the walls and the ice; and by a proper arrangement of straw and faggots, an ordinary cellar, if dry, and well situated, will serve as an ice-house. In some places, caverns in limestone rocks, or excavations with a long circuitous passage, by way of approach, may be used for storing ice.

The only communication between the interior of an ice-house and the external air should be by means of the entrance passage, which may be two or three yards long, and be furnished with three or four doors, only one of which must be left open at once. A portion of the passage may be fitted up with shelves, to serve as a pantry, in which case, four doors are necessary, and the space between the first or outer and the second door, and the space also between the second and third doors, should be filled up with straw, which may be conveniently packed up in large bags, or cushions, and suspended from the ceiling. Barley-straw is the best, on account of its being very flexible. The space between the third and fourth doors forms the pantry, the temperature of which may be reduced by occasionally leaving the fourth or innermost door open for a short time. In some cases, the body of the ice-house is fitted with shelves as a pantry.

The form of ice-house usually adopted in this country, frequently fails in keeping the ice, from not having double walls and double or treble doors, or from imperfect drainage.

Fig. 1209 is the ground-plan, and Fig. 1210 the section of an ice-house of approved construction. Loudon says that it will keep ice throughout the year in any climate, if covered with a sufficient thickness of earth or straw. *a* is the well or cellar for the ice; *b* a drain for carrying off the thaw-water; *c* a trap in this drain, to prevent the external air from communicating with that of the ice-house; and *d* a lead pipe from this trap, connected with a pump at *e*, for pumping up the ice-cold water, for the purpose of cooling wines, or after filtration for drinking. There are five doors to this ice-house, at *f*, *g*, *h*, *i*, *k*; and a vacant space *l*, one foot wide, between the two walls surrounding the cellar, and covering the inner division of the passage *m*. This passage *m* may be used as a pantry, as already noticed. The natural level of the ground is shown at *n n*; and the whole superstructure may be covered in Britain to the depth of two or three feet with earth, planted with ivy, and surrounded with trees.

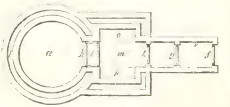

Fig. 1209.

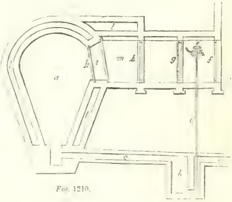

Fig. 1210.

In warmer climates the depth of earth ought to be eight or ten feet. The size of the well ought also to be increased, and a third vacant space round it might be desirable. The space between the door *i* and *k* should be filled up by a barley-straw cushion, and it is desirable to have similar cushions against the doors *g* and *h*, at least during summer. The two recesses *o* and *p* may be increased at pleasure.

In filling an ice-house, the ice should be broken with mallets or stampers to a coarse powder, and well rammed down in the well or pit, keeping the upper surface concave, and adding a little water from time to time, in order to fill up the interstices, and assist the congelation of the whole into a solid mass. It is even recommended to sprinkle the ice with salt water (1 lb. of salt to every gallon of water) from a common watering-pot, at intervals of two feet from the bottom to the top of the mass, an extra quantity being poured on when the filling is completed. The freezing mixture, formed by 1 part salt, and 2 parts pounded ice, will sink a thermometer from the ordinary temperature of a room to 5°; a degree of cold somewhat approaching this being produced in the ice-well, the ice is so firmly compacted together, as to require a pickaxe to break it up the following summer, and the salted ice, according to Loudon, will keep three times as long when exposed to the air as fresh ice.

Snow is preserved in some places in a similar manner to ice, by being rammed down in pits, and well protected from the air at the surface. At Naples, and in the south of Italy, even the poorest persons are accustomed, during the heats of summer, to cool their drink with snow, which is collected from the Apennines, and stored in pits dug chiefly on the northern side of the mountains. The snow is thrown into these pits in broad thick layers, and well pressed together until a considerable mass is collected; the opening is then filled up with branches of trees, dried leaves, or straw; and in some cases, a

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(1) Encyclopædia of Cottage, Farm, and Villa Architecture.

rude stone building is erected over it. A few of the loftiest summits of the Apennines rise above the snow-line, and are therefore covered with snow all the year round; but from the lower ridges, the snow melts away in summer, and it is only by making a careful provision at the proper season, that a supply is kept up during the summer. The lower down the mountain the snow-cave is, the less trouble in getting it at the season when it is most wanted, but the greater the risk of its melting away. The situation for the pit must therefore be carefully selected, and the spot be well shaded by trees, or by some projecting portion of rock, to keep off the rays of the sun. On some rare occasions, a snow shower of considerable thickness will fall during winter on the lower inhabited ridges. An occurrence of this kind produces general rejoicing, for it saves the labour of collecting snow from the heights. Men, women, and children, rush out with shovels, baskets, &c., to gather in their snow-harvest. Immense snow-balls are made, and carefully rolled by the children to the caves. The snow-harvest during winter gives employment to numbers of the peasantry; and the conveyance and sale of the same substance in summer is also a source of constant activity. The task of conveying snow from the mountain caves and distributing it in the various shops of Naples which sell that article only, is performed during the night: mules are loaded with the snow at the mouth of the caves, and they convey it down the mountains to the boats, which take it into Naples; there it is deposited in a large cool building, called "La Dogana della neve;" or, the snow custom house, where retail dealers come from all parts of the town, to get their supply. The snow-trade is in the hands of government, and produces a considerable revenue. The dealers are bound to sell the snow at a fixed price, and are fined if they do not have a sufficient supply. The snow-shops, of which there is one in nearly every street in Naples, are kept open day and night during the season. Snow is also collected in a somewhat similar manner in Sicily, where the great store-house of snow is Mount Etna.

Of late years, ice has become an article of commerce between countries where it is found in abundance, and those where it is found scantily or not at all. The place where this remarkable traffic commenced, is Wenham Lake, about 18 miles from Boston, in the United States of America; and subsequently, some of the Norwegian lakes have furnished abundant supplies. The Wenham Lake Company was formed, and we learn from the *Illustrated London News* some particulars respecting their proceedings In September, 1833, a cargo of ice shipped at Boston, was discharged at Calcutta, and sold at 3*d.* per lb. while the native ice cost 6*d.* It was packed in large cubes, fitting closely together so as to form one solid mass, within chambers of double planking with a layer of well-dried refuse tan or bark between them. The quantity shipped, was 180 tons, of which about 60 wasted on the voyage, and 20 on the passage up the river to Calcutta. Thousands of tons are now annually shipped from Boston to our East Indies, to the West Indian Archipelago, and to the continent of South America. The company have erected extensive ice-houses in London, and at Liverpool, and have arranged for importing into this country thousands of tons of ice every year. The masses are so large, that they expose a very small surface to the action of the air, and hence they suffer but very little loss. It is also stated, that ice frozen upon deep water is more hard and solid than ice of the same thickness obtained from shallow water, and melts more slowly. In Great Britain, the collection and storing of ice is very precarious, on account of the uncertainty of the supply during our mild winters; but in America, where the cold of winter is intense, the cutting, storing, and transportation of the ice is regularly carried on throughout the winter.

Wenham lake occupies an elevated position, and lies embosomed in rugged hills. The lake has no outlet, but is fed by the springs which issue from the rocks at its bottom, at a depth of 200 feet. The ice-house, which is capable of storing 20,000 tons of ice, is built of wood, with double walls 2 feet apart all round, the intervening space being filled with saw-dust. The machinery used for cutting the ice is worked by men and horses. From the time when the ice first forms, it is kept free from snow until it is thick enough to be cut; the cutting being commenced when the ice is a foot thick. A surface of some 2 acres is then selected, which, at that thickness, will furnish about 2,000 tons, and a straight line is then drawn through its centre from side to side each way. A small hand-plough is pushed along one of these lines, until the groove is about 3 inches deep and ¼ inch wide, when the marker, Fig. 1211, is introduced. This implement is drawn by 2 horses, and makes 2 new grooves parallel with the first, 21 inches apart, the gauge remaining in the original groove. The marker is then shifted to the outside groove, and makes 2 more. Having drawn these lines over the whole surface in one direction the same process is repeated in a transverse direction, marking all the ice out into squares of 21 inches. Meanwhile the plough drawn by a single horse follows in these grooves, and cuts the ice to a depth of 6 inches. One entire range of blocks is then sawn out, and the remainder are split off toward the opening thus made with an iron wedge, called an *ice spade*, Fig 1212; when it is dropped into the groove the block splits off with a very slight blow, especially in very cold weather; the labour of *splitting* being slight or otherwise according to the temperature of the air. Low

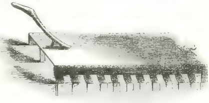

Fig. 1211.

platforms are placed near the opening made in the ice with iron slides extending into the water, and a man stands on each side of a slide armed with an ice hook, Fig. 1213, with which he catches the ice, and by a sudden jerk throws it up the slide upon the platform. In a cold day everything is quickly covered with ice by the freezing of the water on the platforms, slides, &c., and the huge blocks of ice, some of which weigh more than 2 cwt. each, are hurled along these slippery surfaces with great ease. By the side of the platform is a sled of the same height, capable of containing about 3 tons, which when filled, is drawn over the ice to the front of the store-house, where a large stationary platform of the same height is ready to receive its load, which, as soon as discharged, is hoisted a block at a time into the house.

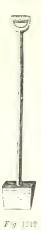
Fig 1212

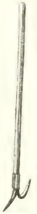
Fig 1213

Forty men, assisted by 12 horses, will cut and stow away 400 tons a day. Sometimes in favourable weather 100 men are employed at once. When a thaw or a fall of rain occurs, the ice is made porous and opaque and unfitted for the market: when snow is followed by rain, and that by frost, the snow-ice thus formed is removed by the *plane*. The operation of planing is somewhat similar to that of cutting. A plane gauge to run in the grooves made by the marker, and which shaves the ice to the depth of 3 inches, is drawn by a horse, until the whole surface of the ice is planed. The chips thus produced are then scraped off, and if the clear ice is not reached the process is repeated. If this makes the ice too thin for cutting, it is left until a few nights of hard frost shall have added below as much as was removed from above.

In addition to filling their ice-houses at the lake and in the large towns, the Company fill a large number of private ice-houses during the winter; all the ice for these purposes being transported by railway. [See APPENDIX.]

We come now to the second part of our subject—the production of ice artificially; the most ancient example of which is probably that carried on in the upper country, near the town of Hoogly, about 40 miles from Calcutta. By a skilful application of the process of evaporation the natives are able to procure a supply of ice during their short winter, viz. from the end of November to the middle of February. The ground where the ice is made is a large open plane: 3 or 4 troughs are formed, each about 120 feet in length by 20 feet in width and 2 feet in depth: the bottom is made smooth and allowed to dry by exposure to the sun. It is covered with bundles of rice-straw to the depth of about a foot, and then loose straw is strewed in, to within 6 inches of the adjoining land. The water to be frozen is contained in pans of unglazed porous earthenware, very much like those put under our garden flower-pots, and these are arranged in regular order close to each other upon the loose straw in rows to the number of 5 or 6,000. The natives fill the pans with soft water by means of small earthen pots, attached to the end of bamboo-rods, long enough to reach half way across the trough. The water is taken from large water-jars sunk deep in the ground near the pits where the ice is stored, and filled from the neighbouring pools or with drainings from the ice. The quantity of water poured into each pan varies from $\frac{1}{8}$ to $\frac{1}{3}$ of a pint, depending upon the clearness of the sky and the steadiness of the wind. The most favourable wind is from the NN. W.: but any point between N. and W. will do, although less ice is produced. If the wind is between E. and S. no ice will be formed. The ice which begins to appear a little before midnight, is carefully watched by persons stationed near each trough. As soon as a slight film of ice appears, the contents of several pans are mixed together, and the freezing liquid sprinkled over the others. The freezing continues till sunrise, when perhaps as much as half an inch of ice will be found in each pan. In very favourable nights the water is entirely frozen. The ice is generally removed by women, 7 or 8 of whom are appointed to each ice-bed: they use a blunt semicircular knife to scoop out the ice, which they throw together with any unfrozen water into earthen vessels placed near them. When these are full their contents are poured into conical baskets, placed over the large water-jars from which the pans are filled; by which means a supply of cool water is collected for the next night's operations. When the ice has been sufficiently drained, it is deposited in wells near the ice-beds; and at night removed to large circular pits lined with mats, and covered over with a straw shed. The heat of the day, even in the ice-making season, is frequently greater than that of the hottest summer days of England, so that after all precautions, a partial thawing goes on in the pits. The water thus produced is carried off through holes in the bottom of the pits to a deep well, which also serves to supply the pans in the ice-bed: thus throughout the process the cold is economised as much as possible. The ice is conveyed in boats to Calcutta by night. When the weather is coldest it is simply packed in bags; at other times in baskets lined with straw mats, and conveyed to the city before sunrise. During the hot season, when ice is most needed, it is scarcely possible to preserve it in any quantity, and the first heavy fall of rain usually melts all that is left of the last ice-making season.

The principle of evaporation has been commonly applied in all ages to the cooling of liquids. A porous vessel which allows a minute portion of the liquid contained in it to ooze out so as to keep the surface constantly moist, gets rid of this surface moisture by converting it into vapour, which is being constantly discharged from it, and as the heat required for the formation of this vapour is derived from the vessel itself and its contained liquid, the temperature of the latter speedily falls. A bottle of water covered tightly with a cloth kept wet and exposed to the sun or to the wind, will in a short time fall many degrees below the temperature of the air.

Sir John Leslie carried the principle of evaporation so far as to be able to freeze water in a few minutes by placing it under such circumstances, as to cause it to form vapour rapidly, and then removing the vapour as fast as it was formed. We will first speak of his method of cooling liquids. It is known that unless means be taken for the absorption of the water evaporated from the porous vessels, the air will become so saturated as not to admit of further evaporation, especially in a confined mass of air; and he therefore proposed to place near, and exterior to the vessel containing the liquid, some substance which absorbs moisture with avidity. Dry flannel was found to absorb very well; as also trap rock and compound clays reduced to a coarse powder and dried before a strong fire; parched oatmeal acts with energy as an absorbent, as also does muriate of lime. But it was found that strong sulphuric acid was the most powerful absorbent, continuing for a long time with slowly diminishing force to attract moisture and capable of having its absorbent powers restored by the application of heat. There are, however, so many and such powerful objections to the habitual domestic use of so highly poisonous and corrosive a substance as sulphuric acid, that we can neither recommend it nor hope to see it adopted; but as this plan may be of use in certain manufacturing processes we gave an outline of Sir John Leslie's method. He says:—"To cool water in any climate or state of the atmosphere, we have only therefore to put it into a small porous vessel, presenting on all sides a humid surface, and to suspend this within a close wide cistern, of which the bottom is covered with a layer of sulphuric acid. The broad surface of the acid absorbing the moisture as fast as it diffuses itself through the confined air, keeps that medium constantly at a point of extreme dryness, and thus enables it to support with undiminished vigour the process of evaporation." He recommends the use of a cistern or *refrigerator*, Fig. 1214, of a broad cylindrical form, from 12 to 16 inches in diameter, composed of dense glazed earthenware. This is to be placed in a cellar or other cool place, and charged with sulphuric acid to the depth of about ½ inch. A porous earthen pot being filled up to the lip with water, is set upon a low porcelain stand in the middle of the cistern, to which the lid or cover is then carefully fitted. The cooling is completed in from 3 to 5 hours, when the water should be removed. The production of cold is greater when the refrigerator is large, or when a small pot is used, insomuch that the effect will be diminished one half, if the humid surface should equal that of the acid. The power of the refrigerator is always the greatest at the season when it is most wanted; that is, a given quantity of water on a hot day can be lowered a greater number of degrees than on a cold day. When the thermometer is at 95° in the open air, the refrigerator will reduce the water in the porous vessel to 59°, but when the thermometer is at 50° the water can be cooled to 32°. By supplying a succession of porous earthen pots, the acid will continue to act till it has absorbed half its weight of moisture, during which time it will have assisted in cooling about 50 times that quantity of water exposed to evaporation. Butter may also be kept cool for the table in summer, by putting it after being washed with water into a wet porous pot, and shutting this up for a couple of hours in the refrigeratory. To cool wine sufficiently, one bottle only is used at a time in the smallest refrigeratory. A sheath of stocking or flannel, previously soaked in water, being drawn over the body of the bottle, it is laid in a reclined position on a porcelain slider near the surface of the acid, and left shut up for 3 or 4 hours.

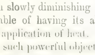

Fig. 1214.

But by the use of the air-pump Leslie showed, in a striking manner, the absorption and disappearance of sensible heat during evaporation. A shallow dish of sulphuric acid was placed on the table of the air-pump, and over this, upon a glass tripod, a metal vessel containing water. On covering this with a receiver, and pumping out the air, the water first discharges the air dissolved in it, and by the rapidity of its evaporation appears to boil. As fast as the vapour is formed it is absorbed by the sulphuric acid, and as the heat necessary to the formation of this vapour is derived from the water itself, the latter quickly loses the heat necessary to its existence in the fluid form, and it becomes solid or freezes. If during this process the bulb of a thermometer be kept in the water, it will be observed that the temperature falls several degrees below the freezing point before congelation takes place; but as soon as it freezes it rises to 32° in consequence of the escape of the residuary latent heat. Leslie proposed this method as a means of procuring ice in hot climates, and suggested for the purpose a large single-barrel air-pump, capable of exhausting 6 or 8 receivers at a time. Attempts have also been made to form ice on this plan on a large scale, by the evaporation of ether contained in a separate vessel under the same receiver with the water, and to pump out the vapour of ether, thus formed, into a separate condenser, so as to be able, for the sake of economy, to use the same ether over and over again. All these plans have failed in practice on account of the comparatively great expense and the small produce of ice.

The production of cold by freezing mixtures depends upon the general law, that in the conversion of a solid into a liquid a quantity of heat, not indicated by, or sensible to the thermometer, is absorbed or disappears, which heat is withdrawn from the surrounding bodies. If the solids be suddenly or rapidly liquefied, the absorption of heat, *i. e.* the production of cold, is very marked. Thus when common salt in fine powder is mixed with snow or pounded ice, these solids suddenly liquefy and run down into brine, which does not freeze till reduced to nearly 0°. A mixture of ice and salt is used by confectioners in the preparation of ices.[1] A mixture of about 3 parts of freshly-gathered, light, flocculent snow, with 2 parts of chloride of calcium, made in earthen vessels previously cooled, will depress the thermometer from 32° to between 40° and 50° below zero, a temperature at which mercury freezes. By the successive application of freezing mixtures in a proper apparatus, Walker succeeded in sinking the spirit thermometer to —91°. Some of the most useful freezing mixtures are given in the following table:—

MIXTURES.	PARTS.	THERMOM. SINKS.
Sal Ammoniac	5	from 50° to 10°
Nitre	5	
Water	16	
Nitrate of Ammonia	1	,, 50° ,, 4°
Water	1	
Sulphate of Soda	3	,, 50° ,, 0°
Dilute Sulphuric Acid	4	
Snow	1	,, 32° ,, 0°
Common Salt	1	
Muriate of Lime	3	,, 32° ,, —50°
Snow	2	
Snow	2	,, —10° ,, —56°
Dilute Sulphuric Acid	1	
Dilute Nitric Acid	1	
Snow, or Pounded Ice	12	,, 18° ,, —25°
Common Salt	5	
Nitrate of Ammonia	5	
Snow	3	,, —40° ,, —73°
Muriate of Lime	4	
Dilute Sulphuric Acid	10	,, —68° ,, —91°
Snow	8	

Ice and salt furnish the cheapest and most convenient freezing mixture; but where ice cannot be procured the salts mentioned in the first two recipes given above may be used, and the salts recovered by evaporation when they have served their purpose, so that they can be used over again. "In employing them to cool a bottle of wine, a vessel should be selected a little larger and nearly as tall as the bottle: this vessel should then be filled with the coldest water that can be procured, and the bottle placed in it: about 4 ounces of the salt in fine powder should be sprinkled upon the shoulder of the bottle, so as, gradually dissolving, to fall or run down its sides; as the salt dissolves, the bottle should be gently turned in the mixture, and kept in it till an immersed thermometer tells us that the temperature is rising, which will be in 20 minutes or half an hour." (*Brande.*) A convenient process for freezing a little water, without the use of ice, is to drench finely-powdered crystals of sulphate of soda with the undiluted hydrochloric acid of the shops. The salt dissolves to a greater extent in this acid than in water, and the temperature may sink from 50° to 0°. The vessel in which the mixture is made becomes covered with hoar-frost, and water in a tube immersed in the mixture is speedily frozen. (*Graham.*)

ICELAND MOSS. *Lichen islandicus.* A lichen, growing freely on the mountains of Scotland, and occasionally employed in invalid diet, to form a jelly which possesses certain tonic and nutritive properties. In the sterile island whose name it bears it is however an important article of food, as a substitute for wheat-flour. It is washed, dried in the sun, and reduced to powder, by stamping in strong bags, after which it only requires sifting to make it applicable to the ordinary purposes of meal or flour. The plant consists of upright leaves, of the peculiar membranous texture common to lichens: these are soft and pliant when moist, but rigid and brittle when dry. The organs of fructification are sprinkled over the exterior surface like small black warts, and the edges of the leaves are fringed with short hairs. The whole plant is smooth and shiny, and inclines to a reddish hue towards the roots.

ICELAND SPAR. Transparent crystalline calc spar, first brought from Iceland. It shows double refraction well.

IGNITION, (from *ignis*, fire,) a property which bodies possess of giving out light whenever their temperatures are raised up to a certain point. The term *incandescence*, (from *incandesco*, to grow very hot,) is generally applied to bodies at a high temperature, which emit light without flame.

ILLUMINATION, ARTIFICIAL. See CANDLE—LAMP—GAS-LIGHTING.

IMPACT, (from *in* and *pango*, to strike,) the meeting of bodies which are in motion, whereby such motion is modified or destroyed. The subject is one of great interest in scientific mechanics. The principal laws of impact are; 1. The common velocity of two non-elastic bodies after impact, when they both move the same way is found by dividing the sum of the products of each body into its respective velocity, by the sum of the bodies; 2. When the bodies meet each other, divide the difference of the products of each mass into its velocity, by the sum of the bodies, for the common velocity after impact. The important law that the angle of incidence is equal to the angle of reflection can also be proved by impact.

IMPENETRABILITY. The two necessary and essential properties of all matter are *extent* or *volume*, and *impenetrability*. It is impossible to form any conception of matter without allowing it some extent, for the smallest conceivable speck must have length, breadth, and thickness; and must therefore occupy a space into which a second speck cannot possibly enter until the first has moved away: this is all that is meant by the impenetrability of matter.

There are however certain cases of apparent penetration of matter: thus, salt may be dissolved in water without increasing the bulk of the fluid, a fact which can only be accounted for on the assumption that the matter of the fluid has interstices or pores, and that the particles of the solid accommodate themselves therein as sand would do if mixed with bullets.

IMPULSE. Any cause by virtue of which velocity is suddenly communicated to a body.

INCANDESCENCE. See IGNITION.

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(1) The cream, or other liquid to be frozen, is contained in a thin metallic pan in the cold brine produced by the melting of the ice. Mr. Masters, the confectioner, in his *Ice Book*, published in 1844, states, that unless the ingredients of the ice be kept in constant agitation during its formation the watery portions freeze out and separate from the richer saccharine matters, and a badly formed ice is the consequence. To prevent this he has invented a kind of churn, which keeps the ingredients in a constant state of agitation during the congelation.

INCIDENCE, Angle of. See HEAT, Fig. 1136.

INCLINED PLANE. See MECHANICS.

INDIAN INK. See INK.

INDIAN RUBBER. See CAOUTCHOUC.

INDIGO. This valuable dye is obtained from tropical plants growing wild, and also cultivated for dyeing purposes, in Asia and America. In the 13th century, Marco Polo found the manufacture of indigo extensive in India, and gave descriptions of the plants which yield the dye, and their mode of treatment, but his accounts were little known or believed, so that long after the dye had been obtained direct from India, under the name of *indicum*, the most erroneous notions prevailed as to its real nature. At Halberstadt, in Germany, it was sought for as a *mineral*, and was included by name in the letters patent granted to some proprietors of mines for the erection of their works.

The product is obtained from numerous species of the genera *Indigofera*, *Isatis*, and *Nerium*, but principally the first named. Thus the *Indigofera tinctoria* of Bengal, Malabar, &c. yields large quantities of the dye, though not of the best quality: a finer kind is the product of *I. disperma*, growing in the East, and also in America, where it yields the Guatemala-indigo: *I. anil*, and *I. argentea*, are other species yielding good indigo, the latter being found also in Africa: *I. glauca* is the species common to Egypt and Arabia: while *I. pseudo-tinctoria*, which is the best of all, is cultivated in the East Indies. *Indigofera tinctoria*, as propagated in the West Indies, is described as having a root about a quarter of an inch thick, and more than a foot long, having a faint smell resembling parsley. From this root issues a short bushy stem of about the same thickness, hard and woody, not rising more than 2 feet. The leaves are winged, or consist of several pairs of leaflets, ranged on each side a long foot-stalk, and having a terminal leaf at the extremity. For about one-third of its upper extent, also, the stem is laden with spikes of very small flowers, destitute of smell, succeeded by long crooked brown pods, inclosing small yellow seeds. Indigo is called "the child of the sun," as it cannot be successfully cultivated anywhere except within the tropics. The Indigoferæ, in common with other leguminous plants, must be considered as having deleterious qualities, but in this, as in many other examples, they are not sufficiently developed to prove injurious. Some of the indigo plants are used as fodder, just as clover, saintfoin, and other members of the same great natural family are with us. Partly on account of the supposed injurious qualities of indigo, but principally, no doubt, through a jealous apprehension that this dye would supersede the British woad, it was denounced in the time of Elizabeth as a dangerous drug, and an act was passed, which remained in force until the time of Charles II., authorizing searchers to burn both it and logwood in all the dye-houses where they were discovered. The prejudice against indigo, both in England and France, is said to have been maintained by the belief that it was a fugitive colour, and injurious to the quality of the wool. After a time, however, when indigo began to reach this country from America as well as Asia, and when the French also brought indigo from the African coast, it gradually took its place among the best dyes, and has now long been recognised as one of extreme value, for which no worthy substitute can be found.

In the eastern mode of cultivating indigo, the seed is sown in March and April, in a light but rich soil, at the rate of twelve pounds of seed to the acre, and the growth of the young plants is so rapid that in June or July they have arrived at maturity, denoted by the expansion of the blossoms, at which time the dyeing principle is most abundant. The first cropping of the plants then takes place, but a second, third, and even a fourth may follow in the same season. The colouring matter is obtained from the whole plant, either by fermentation of the fresh leaves and stems, or by maceration of the dried plant. In the former case the fresh plants, as they are cut off and brought in from the field, are placed in a large stone cistern, which is filled with them to within a few inches of the brim. In order that they may not swell and rise out of the vat during fermentation, beams of wood are laid on them and braced down with twigs of bamboo. Active fermentation soon commences, and is revealed by the frothy bubbles rising to the surface, at first white, then grey-blue, and at last deep purple, when a copper coloured scum also spreads around. The fermentation is now at its height, and the liquor agitated: when it begins to subside the liquor is drawn off into a lower cistern, where it exhibits a glistening yellow colour, changing to green. Several men are then employed in beating the liquor with oars or shovels, while others take off the bamboos and clear out the upper vat of the waste material, (which is dried for fuel,) and prepare it for a fresh charge. The beating of the liquor is continued for an hour and a half; and by its means a great quantity of carbonic acid is disengaged, and the particles of indigo get thoroughly exposed to the atmosphere, and obtain their requisite supply of oxygen; after which they agglomerate in flocks or granulations, the whole assumes the colour of Madeira wine, and on the cessation of the beating, the indigo gradually subsides, leaving the liquor transparent. When the grain is precipitated, the clear liquor is drawn off and allowed to run to waste in some spot where it will not mingle with a brook or pond frequented by cattle, (on account of its deleterious qualities.) A labourer then enters the vat, sweeps up the thick and pulpy matter, and discharges it into a cistern alongside of a large boiler, into which it is passed through a strainer, and heated to ebullition. By this process it is enriched in colour, and increased in weight. From the boiler the mixture is run into a receiver called the *dripping vat*, which has a false bottom of woollen web, through which the liquor filters. As long as it passes through turbid, it is pumped back again into the receiver, but when it runs clear, it is allowed to drain through slowly. The day following, all the drained indigo is put into a strong bag and squeezed in a press. It is then taken out, cut into cubes with a brass wire, and placed upon wicker-work shelves to dry. A whitish efflorescence soon covers the pieces. This is brushed off; but in some places the cakes are fermented by placing them in heaps in a cask until moisture exudes, after which they are finally covered with a white meal. Five or six days' drying completes the process, and fits them to be packed for exportation.

When the dried plant is used instead of the fresh, (and this is said to be the better method,) the indigo croppings are spread in the sun, like hay, and when dried, are stored in magazines till a sufficient quantity is collected for the purposes of the manufacture. The dried plants are infused in the steeping vat with six times their bulk of water, and are allowed to macerate for two hours with continual stirring till all the floating leaves sink. The fine green liquor is then drawn off into the second vat, and beaten as before. Hot water is sometimes used for macerating the plant, but this does not appear to be necessary.

In the years 1859-60-61, 63,237, 77,231, and 83,109 cwts. of indigo were imported in cubic cakes. In this form it is friable, more or less brittle, and of various shades of a peculiar deep blue. When rubbed with a hard body it exhibits a copper-red appearance. The best indigo is so light that it will swim upon water. Its quality depends upon the species of plant, the soil and climate in which it was grown, and the details of the manufacture. It has not yet been determined in what form the indigo exists in the plant. According to Schunk's experiments on woad (Manchester Memoirs, 1855), it is probable that a principle named by him *Indican*, of a yellow colour, and of the composition $C_{52}H_{33}NO_{36}$? occurs naturally in the plants, and that it is from the decomposition of this body that the indigo is produced.

The blue colouring matter of indigo is soluble neither in water nor in alkaline leys; but by being treated by deoxidising agents in contact with water, it takes up an additional equivalent of hydrogen, and forms white indigo, or reduced indigo, which is soluble in alkaline leys; the alkaline solution by exposure to the air absorbing oxygen, and passing into the form of insoluble indigo blue. [See CALICO PRINTING, Fig. 417.]

Thus we have —

Indigo blue . $C_{16}H_5NO_2$ = Indyl. . . . . . . In.
White indigo $C_{16}H_6NO_2$ = Hydride of indyl. In.H
Isatin . . . . $C_{16}H_5NO_4$ = Oxide of indyl. . $In.O_2$

Schunk found that woad does not contain indigo ready formed, either blue or colourless; that the indigo-producing substance is soluble in water; and that the blue colouring matter in watery extracts of the plant is neither produced nor prevented by oxygen or the alkalies, but that the decomposition of the indican afforded indigo. By heating it with sulphuric or hydrochloric acid it was decomposed, and indigo blue, indigo red, and a kind of sugar, *Indiglucin*, $C_{12}H_{10}O_{12}$, were formed.

Indican is a yellow, transparent, non-crystallisable substance, very deliquescent and soluble in alcohol, and in ether. It has a slightly bitter, nauseous taste, and when boiled with caustic alkali gives off ammonia. A solution of indican becomes bright yellow when mixed with alkali, lime, or baryta. Acetate of lead produces a sulphur yellow precipitate in the alcoholic solution, but not in its aqueous solution until ammonia be added. Solutions of indican must be evaporated without heat, otherwise the aqueous solution will undergo a complete change, showing how necessary it is to avoid the use of boiling water in preparing indigo on a large scale.

The indigo of commerce contains several substances in addition to its important constituent, indigotin, such as indigo brown and indigo red, which must be regarded as impurities. The indigo blue, or indigotin, may be separated by sublimation. If a small quantity of indigo be heated between two watch-glasses, so as to protect it from the air, a portion will be decomposed, but another portion will be sublimed and condensed in light copper-coloured six-sided crystals. A better plan, however, is the following:— 4 oz. of indigo in fine powder, and 4 oz. of grape-sugar are put into a flask of the capacity of 10 pints; 6 oz. of a saturated solution of caustic soda are added, and the flask is filled up with boiling alcohol. The flask is closed to keep out the air, and the mixture after agitation is set aside. In a few hours it becomes clear; the yellowish red solution is drawn off with a syphon, and if left exposed in open vessels it rapidly absorbs oxygen, becomes brown, and deposits crystals, which, after being first treated with alcohol, and then with hot water, and dried, form pure indigo blue, of which good indigo should yield nearly half its weight. Indigotin fuses at about 550°, and produces a purple vapour.

Indigo forms several compounds with sulphuric acid, one of which is produced by triturating commercial indigo with six times its weight of fuming sulphuric acid, when heat is evolved and a blue solution formed, which is used for dyeing cloth under the name of *Saxony blue*. Common sulphuric acid may be used for the purpose, but more than double the quantity is required, and it must be heated to more than 130° or 140.° In this way an acid known as the *sulphindylic* is formed, but for these compounds, and for various other particulars respecting indigo, we must refer to the Appendix.

We must not, however, omit to state that one of the most curious and valuable properties of indigo is the comparative facility with which it loses its colour, becomes soluble so as to allow it to be used as a dye, and then by exposure to the air reassumes its blue tint and becomes again insoluble. [See DYEING.] This change takes place when indigo is brought into contact with certain deoxidizing agents and an alkali, and it is probable that under these circumstances the indigo returns to the state in which it existed in the plant. In preparing his *indigo-vat* the dyer uses 5 parts of powdered indigo, 10 parts of sulphate of iron, 15 parts of hydrate of lime, and 60 parts of water: these are agitated together in a close vessel, and then left to stand. The salt of iron in conjunction with an excess of lime reduces the indigo to the soluble state; a yellowish liquid is produced, from which, if oxygen be carefully excluded, the *white* or *deoxidized* indigo is precipitated in a flocculent form by an acid, such as the acetic or hydrochloric. Cloth steeped in the alkaline liquid, and then exposed to the air, acquires a deep and permanent blue tint, by the absorption of oxygen and the deposition of solid insoluble indigo in the substance of the fibre. A mixture of dilute caustic soda and grape-sugar may be used instead of the salt of iron and lime, in the above process; the sugar becomes oxidised to formic acid, and the indigo is reduced. Decaying vegetable matter may also be used instead of the sulphate of iron.

INFUSION.—See DECOCTION.

INK is variously composed according to the purposes to which it is to be applied. *Common writing ink* is the pertannate of iron, mixed with a little gallate, held in suspension in water by means of gum or some other viscid substance. The gum also prevents the ink from being too fluid, and also serves to protect the vegetable matter from decomposition. A very good ink may be formed from the following recipe: Take Aleppo galls finely bruised, 6 oz.; crystallized sulphate of iron, 4 oz.: gum arabic, 4 oz.; water, 6 pints. Boil the galls in the water, for about 2 hours, occasionally adding water to supply the loss from evaporation; then add the other ingredients, and keep the whole for two months in a wooden or glass vessel, which is to be occasionally shaken. Then strain the ink into glass bottles, adding a few drops of kreosote to prevent mouldiness.

When the ink has not been kept long enough, and is pale in writing, it becomes black in consequence of the oxygen of the air converting the protogallate and prototannate of iron into pergallate and pertannate; but when writing becomes yellow and indistinct from age, it is from the decay of the vegetable portion of the ink, little more than peroxide of iron being left on the paper. By the careful application of infusion of galls the writing may be rendered blacker and more legible, or by washing the writing with a weak solution of oxalic or hydrochloric acid, and then applying an infusion of galls. When the writing paper has been made from inferior rags, bleached with excess of chlorine, the best ink becomes discoloured. Logwood, sulphate of copper, and other ingredients are occasionally added to ink, but their effect is injurious.

Blue ink has of late years been much in request: the colouring matter is said to be sulphate of indigo and tannogallate of iron; or, according to another recipe, Prussian blue dissolved in water by means of oxalic acid.

Red ink is usually made by boiling about 2 ounces of Brazil wood in a pint of water for a quarter of an hour, and adding a little gum and alum. A superior description of red ink may be formed from an ammoniacal solution of carmine. [See CARMINE.]

The great merit of our common writing ink is the freedom with which it flows from the pen, allowing of rapid writing; and the manner in which it bites into the paper, so as not to be removed by sponging. The great defect is want of durability. Such inks partake rather of the nature of dyes. The writing ink of the ancients, on the contrary, is characterised by great permanency; its basis was finely divided charcoal mixed with some mucilaginous or adhesive fluid. *Indian* or *China ink* is of this character: it is formed of lamp-black and size or animal glue, with the addition of perfumes, not necessary, however, to its use as an ink, and is made up in cakes. It is used in China with a brush both for writing and for painting upon Chinese paper; and it is used in other countries for making drawings in black and white; the different depths of shade being produced by varying the dilution with water. The lamp-black must be exceedingly fine, and the ink be prepared with great care.

The permanent character of carbonaceous inks would recommend them to more general use, if a sufficiently fluid vehicle could be found for them. According to Professor Traill, an acetic solution of gluten, forms an excellent basis of a durable and indelible writing ink. The gluten is obtained as usual by kneading the dough of wheat flour in a stream of water until the starch is completely separated: the gluten should be kept from 24 to 36 hours in water, and then be digested in acetic acid of specific gravity 1·033 to 1·034 in the proportion of 3 parts gluten to 20 of the acid. By means of a gentle heat a greyish white saponaceous fluid is obtained, which will keep for a long time. The colouring matter is from 8 to 12 grains of the best lamp-black, and 2 grains of indigo thoroughly incorporated with each fluid ounce of the vehicle. An agreeable aroma may be imparted to the ink by digesting bruised cloves, pimento or cinnamon in a portion of the original acid. This ink is not adapted for writing on parchment, but may be used on paper with a steel pen, which, however, should be washed after use.

Printer's ink is of two kinds, one for letterpress and the other for copper-plate printing. The former is prepared by boiling linseed or nut-oil in an iron pot: it is kindled and allowed to burn for half-an-hour: the vessel is then closely covered over to extinguish the flame: it is again boiled in order to give it the proper drying character, and it is then mixed with lamp-black for black ink; or vermilion for the finer works in red ink; or the pigment is varied according to the colour. For copper-plate-printer's ink the oil is less boiled, and the carbon used is Frankfort black.

Marking ink, used for marking linen, is a solution of nitrate of silver written with a pen upon the linen previously moistened with an alkaline solution, such as potash or soda. In this operation oxide of silver is precipitated upon and combines with the cloth in a very firm manner. The bottles of indelible marking-ink are prepared by dissolving 2 drachms of pure nitrate of silver and 1 drachm of gum-arabic in 7 drachms of distilled water coloured by a little China ink. The preparatory liquid is made by dissolving 2 ounces of crystallized carbonate of soda and 2 drachms of gum-arabic in 4 ounces of water. A much more convenient marking ink is that used by the bleachers, viz. coal-tar, made sufficiently thin with naphtha to write with.

Sympathetic inks are noticed under Cobalt. The inks for what are called *Chemical Landscapes*, have lately been increased in number. Acetate of cobalt affords an azure blue; chloride of copper a gamboge yellow; chloride of cobalt an Olympian green, and bromide of copper a fine brown. [See Appendix.]

INTAGLIO.—See Seal-engraving.

INTRADOS and EXTRADOS, the inferior and exterior curves of an arch. See Bridge, vol. i. p. 198.

INULINE. See Starch.

IODINE, an elementary substance (I. 127), was discovered in 1811 by M. Courtois of Paris, a manufacturer of salt-petre, in the mother-liquors of that salt. Its affinity for other substances is so strong that it does not occur in nature in a separate state. It is found combined with potassium and sodium in many mineral waters, and also in a minute proportion in sea-water, from which many marine plants and animals have the power of separating it and accumulating it in their tissues. It is also found in a few minerals.[1] Much of the iodine of commerce is prepared at Glasgow from the kelp of the western coast of Ireland and the western islands of Scotland; and the process for obtaining it has been described by Professor Graham.[2] The sea-weed thrown upon the beach is collected, dried and burned in a shallow pit, in which the ashes accumulate and melt by the heat. The fused mass, broken into lumps, is kelp, which was formerly prepared for the sake of its carbonate of soda, varying from 2 to 5 per cent. The long elastic stems of the *fucus palmatus* are said to afford most of the iodine contained in kelp. The kelp is broken up small, treated with water, the solution filtered and evaporated to a small bulk, the chloride of sodium, carbonate of soda, chloride of potassium, and other salts being removed as they successively crystallize. A dark brown mother-liquor is left, which contains nearly all the iodine: this is mixed with sulphuric acid and peroxide of manganese, and heated gently in a leaden retort *a*, Fig. 1215, of a cylindrical form, supported in a sand bath, and heated by a small fire below. The retort has a large opening, to which a capital, *b c*, is luted, containing two openings of unequal size, *b c*, closed by leaden stopples. A series of bottles *d*, having each two openings, are luted together as shown in the figure, and are used as condensers; the prepared ley being heated to about 140° in the retort, the manganese is introduced. Iodine immediately begins to come off, and collects in the condensers. The progress of its evolution is watched by occasionally removing the stopple at *c*, and additions of sulphuric acid or manganese are made at *b* if necessary. The success of the operation depends upon its being slowly conducted, and upon the proper management of the temperature. The theory of the operation is similar to that of the process for preparing chlorine [See Chlorine]. The manganese, however, is not indispensable in this process, for iodide of potassium or sodium, heated with excess of sulphuric acid, evolves iodine.

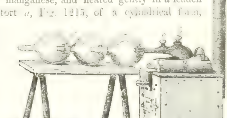

Fig. 1215. Iodine still.

Professor Graham has recently examined the ashes of sea-weeds used as fuel in the island of Guernsey. "Having observed that large quantities of deep sea fuci were collected by the inhabitants, spread out to dry in the fields, then used as common fuel in their houses, and the ashes carefully saved as a valuable manure for their land, it occurred to him that these ashes might contain a larger quantity of iodine than the ordinary kelp, both on account of the source from whence the fuci were derived, and the comparatively low temperature at which the combustion was effected; for there could be little doubt that in the manufacture of Scotch kelp a portion of the iodide of sodium present was lost by sublimation." On examining these ashes they were found to be very rich in iodine.

Professor Bechi of Florence has described an easy method for extracting iodine from mineral waters. This method is founded on the property which charcoal has of retaining iodine, and afterwards readily yielding it to other substances. The iodides contained in the mineral water are first decomposed by means of chlorine or acids, and the water is then passed through a filter containing a large quantity of calcined lamp-black: after passing through several layers of this charcoal, the water is completely deprived of its iodine. Having washed the charcoal, it is mixed with hydrated oxide of iron, placed on a filter, and water poured over it several times to remove all the iodide of iron. The solution of iodide of iron being treated with sulphate of copper, iodide of copper is formed, which, being heated in a retort with oxide of manganese and sulphuric acid, the iodine is distilled over. The charcoal used in this operation is washed with dilute hydrochloric acid, to separate any remaining oxide of iron, and thus purified, it is used for another operation.[3]

Iodine crystallizes in plates or scales of a bluish-black colour, and imperfect metallic lustre. Its density is 4·948. It fuses at 225°, and boils at 347°, emitting a vapour of a beautiful violet colour, whence the name of this substance from ἰώδης, violet-coloured. It is slowly volatile at common temperatures, exhaling a peculiar odour something like that of chlorine. The density of the vapour is 8·716. It dissolves in about 7,000 parts of water, to which it gives a brown colour; but in alcohol it dissolves freely. It stains the skin of a deep brown, which is not permanent. It acts with energy on the animal system, and is much used in medicine.

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[1] A copious list of the sources of iodine is given in Gmelin's Hand-book of Chemistry, vol. ii.

[2] Elements of Chemistry, 1842.

[3] Signor Bechi's Essay obtained the prize offered by the Academy of the Fine Arts of Florence, in 1848, for his answer to the question—"To find an economical and easy means of extracting iodine, not only from all its natural combinations existing in the soil of Tuscany, but also from every other artificial combination." The Essay is given in the "Journal de Pharmacie," July 1851, and also in the "Chemist," for September 1851.

The chief use of iodine in the arts arises from its characteristic property of producing a splendid blue colour by contact with starch. A liquid, containing one 450,000th of its weight of iodine, receives a blue tinge when a solution of starch is added to it. In order to act as a test, the iodine must be free or uncombined, for which purpose, when the presence of a soluble iodide is suspected, a small quantity of chlorine water, added to the solution, will liberate the iodine so as to allow it to act on the starch. Iodine and bromine are also used to form the film of iodide or bromide of silver in the silver plates of the daguerreotype.

Iodine unites with hydrogen, forming hydriodic acid (HI.), and with oxygen forming iodic acid, IO_5, and hyperiodic acid, IO_7.

IPECACUANHA, the root of several plants growing in South America. They all contain similar ingredients, but differ in the amount of the active or emetic principle, called *emetina*, contained in them. The best ipecacuanha is the annulated: it is produced by the *Cephaelis Ipecacuanha*, a small shrubby plant, of which there are 3 varieties, the *brown*, the *red*, and the *grey*, or *grey-white*, also called *greater annulated ipecacuan*. This is the only sort sent from Rio Janeiro, and is sometimes called *Brazilian* or *Lisbon ipecacuan*. It is sent in bales and barrels. "The root is in pieces from 2 to 6 inches long, and about the thickness of a straw, much bent or twisted, either simple or branched, with a remarkably knotty character, owing to numerous circular depressions or clefts, which give the whole an appearance of a number of rings; and hence the term *annulated*. It consists of a central portion called *meditullium*, and an external portion called the *cortical* part. Each contains *emetina*, but by far the greater part of it exists in the cortical. Of the 3 varieties of annulated ipecacuan, the brown contains 16 per cent. of emetina, while the red contains only 14 per cent." The *undulated* or *amylaceous* ipecacuan, contains only 6 per cent. of emetina, with 92 per cent. of starch. Emetina is a white powder: it is a powerful poison, and $\frac{1}{16}$th of a grain, or less, acts as a violent emetic.

IRIDIUM, (Ir. 98·56.) See APPENDIX.

IRON (Fe. 28) is more extensively diffused throughout the crust of the earth, and in greater abundance, than any other metal: indeed, it is scarcely possible to analyse an inorganic body without finding it: and its importance is equal to its abundance, for there is no other substance which possesses within itself so many valuable properties, or is so well adapted to form the tools, machines, and engines, which have assisted, and still continue to maintain, the dominion of mind over matter. Admirably adapted also to the wants of man is the position of iron ore in the earth, for it is often found in immediate connexion with the coal and the limestone flux required for its reduction: "an instance of arrangement," as Conybeare well remarks, "so happily suited to the purposes of human industry, that it can hardly be considered as recurring unnecessarily to final causes, if we conceive that this distribution of the rude materials of the earth was determined with a view to the convenience of its inhabitants."

SECTION I.—METALLURGICAL HISTORY OF IRON.

Iron was known at a very early period in man's history. We read in Gen. iv. 22, that Tubal Cain was an instructor of every artificer in brass and *iron*, and in many parts of the sacred record we have evidence of the extensive use both of iron and steel. Among the ancient Greeks bronze seems to have preceded the use of iron, and the term used to designate the smith's calling signified "a worker in bronze," a term afterwards applied also to workers in iron. Many passages in Homer show that iron was well known in his time, and there can be no doubt that the word σίδηρος has been correctly translated into *iron*, for in the Odyssey there is a simile commencing thus: "As some smith or brazier plunges into cold water a loudly-hissing great hatchet or adze, tempering it, for hence is the strength of iron," &c.; thus proving that the art of tempering steel was practised as it is at present in the manufacture of cutting-tools, and that the worker in iron or steel was called a brazier. In later times, steel was abundant in Greece. Æschylus (born 460 B.C.) includes all the countries on the shores of the Black Sea under the general term Scythia or Chalybia. "He speaks of the Chalybes as workers in iron, of Scythia as a land, 'the mother of iron;' and of the sword, as 'sharp iron, the bitter appeaser of strife;' 'the Pontic stranger born in fire;' and also as 'the Chalybian stranger come out of Scythia.' From this time dates the use of the word *chalybs*, in Greek, as signifying steel of the best quality; whence it passed unchanged into the Latin language, and may at the present day be recognised in our own, in the expression *chalybeate* waters, *chalybeate* medicines, &c., in consequence of some commercial transactions which took place more than twenty-three centuries ago between Greece and a country on the Black Sea."[1]

The Romans had an early acquaintance with iron. Diodorus Siculus mentions Æthalia (Elba) as being celebrated, as it now is, for the richness and abundance of its iron ores. Pliny the elder, after enumerating many of the uses of iron in his time, says, "Yea, in one word, we use it to all other necessary uses of this life." This writer refers to Spain as being celebrated for its iron manufactures. But although iron was well known to the Romans, it

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(1) In Mr. Arthur Aikin's "Illustrations of Arts and Manufactures," published in 1841, are four excellent papers, read before the Society of Arts, entitled, "The Antiquarian and Metallurgical History of Iron."

appears from the evidence afforded by the excavations of Pompeii and Herculaneum, that articles of bronze were in general use in the middle of the first century, when those cities were overwhelmed. It is difficult to imagine how bronze and iron should ever be considered as equally applicable to the same uses. "In all the Latin writers, *ferrum*, iron, is the most common name for a sword, but the swords which have been found in these towns are of bronze, as also are the points of spears. Poll-axes and other sacrificing instruments have been found of the same material: even surgeons' instruments, 40 in number, some with cutting edges, and all of bronze, were discovered."

The earliest method of smelting iron seems to have been in furnaces erected on the summits of hills for the sake of currents of air, the furnaces being perforated on all sides with holes, through which the air was driven when the wind blew: the ore was interstratified with charcoal, large quantities of which were added from time to time, and the operation lasted two or three days. Mungo Park, in his Travels in Africa, describes one of these furnaces, which is probably a type of the ancient model. A furnace similar to this was probably used by the ancient Britons, who are supposed to have obtained their knowledge of the art of smelting iron from the Phenicians, who traded with them for tin. Strabo mentions iron as one of the exports of Britain, so that it seems pretty evident, that prior to the Roman invasion the Britons were acquainted with the art of working iron: indeed, the scythes, hooks, broadswords, and spears, with which they opposed their invaders, are evidences of the fact.

Mr. Mushet, in his valuable "Papers on Iron and Steel," remarks on the extreme slowness of these air-bloomeries. "A long and continued cementation of the ore in contact with the fuel was necessary to dispose the metallic particles to unite. A too rapid exposure to a high temperature would be apt to unite a considerable portion of oxygen with the ore, which in this way would acquire a considerable degree of fusibility: this would not only diminish the quantity and quality of the iron, but retard the general operation. To render the quality of the iron homogeneous, masses of iron ore would be used as nearly of one size as possible, which would give rise to a rejection in part of the small, or dust ore, generally the richest of the vein. That this practice prevailed to a considerable extent in Gloucestershire, is evident from the large quantities of small *mine*[1] found from time to time in the old caverns or weeldons of the mountain limestone formation. These acknowledged evils undoubtedly affected the economy and prosperity of the trade, until some more fortunate or more ingenious worker applied the bellows to the art of iron making, which gave rise to the blast-blowing, and occasioned a great revolution and improvement in the fabrication of iron."

When the Roman Conquest was secure the useful arts were carried on in Britain to an extent before unknown in the island. After the arrival of Adrian, (A.D. 120,) the *fabrica*, or great military forge, was established at Bath: and similar establishments were formed in different parts of the country. The situation of Bath was well adapted to such an establishment, from its vicinity to the hills of Monmouthshire and Gloucestershire, where iron ore and wood were plentiful. There is abundant evidence of the industry of the Romans in working the iron mines of Britain until their final abandonment of the island about A.D. 409. Immense beds of iron cinders have been discovered in the Forest of Dean in Monmouthshire, in Yorkshire, and other counties, among which have been found Roman coins and the remains of altars inscribed to the god who presided over iron. Many of these heaps are called *Danes' cinders*, from the idea, probably a correct one, that during the occupation of England by the Danes they carried on the smelting of iron extensively. From the rude method of smelting in these early times, a portion only of the ore was reduced, and it has been found profitable in modern times to smelt these cinders over again. Mr. Mushet states, that for nearly 200 years the blast-furnaces in the Dean Forest used nearly one-half of the furnace burden of these slags or cinders, which were found highly advantageous to mix with the calcareous ores of the district.

In the interval between the Saxon and the Norman conquest scarcely any notices of iron are to be found. The Anglo-Saxons bestowed especial honour on the best artificers of swords, arms, and armour. Gloucester was long celebrated for its iron forges, and it is mentioned in Doomsday-book, that scarcely any other tribute was required from that city than 36 dicars (of 10 bars each) of iron, and 100 iron rods for nails or bolts for the use of the royal navy. From the Conquest to the death of John, iron and steel were imported from Germany and other countries, the German "merchants of the steel-yard" probably deriving that title from the article imported by them, and sold at a place called "the Steel Yard." The art of making defensive armour was during this period carried to great perfection, and a smith or armourer was attached to the establishment of every knight.

Wood-charcoal still continued to be used in smelting iron, so that the iron mines were all situated in the wooded districts of England. Iron must have been scarce, for in the 28th of Edward III. its exportation was prohibited. Up to this time all articles of iron were forged, the art of casting not having been invented, and it has not been determined at what time castings first came into use. It appears, however, that towards the end of Elizabeth's reign, the English first attempted to substitute iron for bronze in the casting of cannon, but the art was probably practised long before in the production of other articles.[2]

During the 14th and 15th centuries England was supplied by Germany and Spain with various articles in iron and steel. In 1483 the home manufacturers complained of this to the Legislature, which led to the passing of an act prohibiting the importation of a variety of articles which could be made at home.

[illegible] Iron Trade, 1841.

In the reign of Elizabeth we find the ingenious Camden lamenting the decay of our forests in consequence of the extension of the iron trade. Several attempts were made in this reign to lessen the consumption of wood, and to limit the erection of iron works; and it was not until the scarcity of charcoal had stopped many iron-works, that attempts were made to smelt iron ore by means of pit coal. Prior to the year 1272 coal had been wrought at Newcastle, and large quantities of it continued to be exported annually to Holland and the Low Countries for the use of the smithy, but it was not thought profitable to smelt by means of coal until Dud Dudley set the example. The name of this person deserves to be enrolled on the same bright page as that which contains the names of Brindley, Arkwright, Watt, and other illustrious men who have so greatly contributed to raise England to her present high position as a manufacturing and commercial nation. It appears, from the interesting account which he has left of his own proceedings, that in 1619, at the age of 20, he quitted the University of Oxford in order to manage three iron-works of his father's in the chase of Pensnet in Worcestershire. Wood having become scarce in the neighbourhood, and pit coal abounding near the furnace, he determined to make trial of it, and was so successful, that he applied for a patent for his invention, which was granted for 31 years. In the year after the date of the patent, Dudley's iron-works were destroyed by a great flood, "to the joy of many iron-masters, whose works escaped the flood, and who had often disparaged the author's inventions because he sold good iron cheaper than they could afford it, and which induced many of the iron-masters to complain unto King James, averring that the iron was not merchantable. As soon as the author had repaired his works and inventions, to his no small charge, they so far prevailed with King James, that the author was commanded, with all speed possible, to send all sorts of bar iron up to the town of London, fit for making of muskets and carbines; and the iron being so tried by artists and smiths, that the iron-masters and ironmongers were all silenced until the 21st of King James."

In this year, 1624, was passed the justly celebrated act for the abolition of monopolies, except patent rights for 14 years to the first inventors of processes or manufactures. Dudley's patent was limited to this term, and he says, that he "went on cheerfully, and made annually great store of iron, good and merchantable, and sold it at 12*l.* per ton. He also made various cast iron wares, such as brewing cisterns, pots, mortars, &c., better and cheaper than any yet were made in these nations with charcoal." But so slow are ordinary minds to adopt new ideas, or to vary the ordinary routine of their proceedings, that the iron-masters continued to oppose, and succeeded in getting poor Dudley turned out of his iron-works. How this was effected, would, he says, be "over long to relate;" but we can well imagine the long course of opposition, of petty annoyance and vexation, inflicted by his rivals, to say nothing of positive wrongs, of combinations among masters and men to oppose a man who was adopting a process the value of which they had not the sagacity to perceive. Dudley proceeded to Himley furnace in Staffordshire, "where he made much iron with pit-coal; but wanting a forge to make it into bars, was constrained for want of stock, to sell the pig iron unto the charcoal ironmasters, who did him much prejudice." After this he erected a large furnace, "27 feet square, all of stone," at Hascobridge, in Staffordshire, "where he made 7 tons of iron per week, "the greatest quantity of pit-coal iron that ever yet was made in Great Britain. Near which furnace the author discovered many new coal mines ten yards thick, and iron mine under it, according to other coal works; which coal works being brought unto perfection, the author was, by force, thrown out of them, and the bellows of his new furnace and invention, by riotous persons, cut in pieces, to his no small prejudice and loss of his invention of making of iron with pit coal, &c.; so that being with law-suits and riots, wearied and disabled to prosecute his art and invention at present, even until the first patent was extinct." Poor Dudley lost most of his property, and was imprisoned for debt; and when Cromwell came into power, he had the mortification of seeing a patent granted to one Captain Buck, for making iron with pit-coal: he states that Cromwell and many of his officers were partners in the scheme, which, however, failed. At the Restoration, Dudley presented a memorial to Charles II; it is an exceedingly interesting document, and contains a masterly epitome of the iron trade up to the time of its composition. It appears strange to us that the force of such reasoning as the following could be resisted, especially when the prize to be gained by yielding to it was iron! After stating that God of his infinite goodness had bestowed upon this country abundance of iron, coal and lime, and that the wood had long been exhausted, he proceeds thus:—"Now, if the coals and ironstone so abounding, were made right use of, we need not want iron as we do; for very many measures of ironstone are placed together under the great ten yards thickness of coal, and upon another thickness of coal, two yards thick, not yet mentioned, called the bottom coal, or heather coal, as if God had decreed the time when and how these smiths should be supplied, and this island also with iron; and most especially, that this coal and ironstone should give the first and last occasion for the invention of making iron with pit-coal, no place being so fit for the invention to be perfected in as this country, for the general good; whose lands did formerly abound in forests, chases, parks, and woods, but exhausted in these parts."

Dudley does not seem to have been successful in his application, and with him died, for a time, the art of making iron with pit-coal. The art of converting coal into coke was known and is described by Dr. Plot, in his History of Staffordshire, published in 1686, who says, that it is "fit for most other uses, but for smelting, fining and refining of iron, it cannot be brought to do, though attempted by the most skilful and curious artists." Our chemists at this time were too much occupied in attempting to transmute the baser metals into gold, to attend to the apparently commonplace and inglorious problem, how to smelt iron with pit-coal.

It was not until 1713 that we hear of any further attempts in this way, when Mr. Darby, of Colebrook Dale, is referred to as smelting iron with pit-coal. The process, however, must have been ill understood, and little known, for in 1747 it is stated in the Philosophical Transactions, as a sort of curiosity, that "Mr. Ford, from iron ore and coal, both got in the same dale, makes iron brittle or tough, as he pleases; there being cannon thus cast, so soft as to bear turning like wrought-iron."

Although the demand for iron was every year rapidly increasing, the yield of our iron furnaces was almost as rapidly diminishing. Instead of relying upon our inexhaustible supply of coal and iron to meet the demand, our ancestors imported vast quantities of iron from Russia and Sweden. At length, however, the steam-engine, under the guidance of Watt, entered into the service of industry, and gave such a stimulus to our great branches of manufactures, that vast systems of iron machinery were being constantly demanded. Then it was that the coal and the iron-stone were made to act upon each other, and the impulse once given, the manufacture advanced with accelerated velocity; and from 61,300 tons produced in 1788, we have in 1860 the enormous amount of 3,826,752 tons.

While the change in fuel was being brought about, the manufacture declined so rapidly, that in 1740, the number of furnaces in England was 59, being only three-fourths of their previous number, and the annual produce was only 17,350 tons. As the use of coke became understood, the manufacture revived, so that in 1788 the number of tons of pig-iron produced was 61,300, as already stated; in 1796 the quantity was increased to 108,793 tons; in 1806, to 250,000 tons; in 1820, to 380,000 tons; in 1827, to 654,500 tons; in 1845, to 1,250,000 tons; in 1851, to 2,500,000 tons; and in 1859, to 3,712,904 tons. In this year the value of our exports of pig-iron, bar, bolt and rod, railway iron, iron wire, cast and wrought iron, and unwrought steel, amounted to £12,323,093. In 1861 our exports of pig-iron were of the value of £1,047,318; of bar iron, bolt and rod, £1,885,605; of railway iron of all kinds, £2,903,357; of iron wire, £207,317; of cast-iron £701,214; of wrought-iron of all kinds, £2,868,923; and of unwrought steel, £727,840.

In 1860 no less than 3,826,752 tons of pig-iron were manufactured of the value of £12,703,950, being the production of 582 furnaces in blast in that year, giving an average of 6,575 tons per furnace, or about 126 tons per furnace per week. In 1740 the weekly yield was only 5 tons 13 cwt. per furnace. In 1788 it was 15 tons 6 cwt.; in 1796 it had risen to 20 tons 2 cwt.; in 1827 to 47 tons 6 cwt.; and in 1845 to 100 tons. In an emergency as much as 200 tons have been produced from one furnace in a week.

For the changes that have taken place in the supply of ore since this article was written, we must refer to the Appendix, as also for recent improvements in the manufacture.

The locality of the manufacture has also been affected by the change of fuel. In 1740 Gloucester was the largest iron producing county in Great Britain. Sussex had the greatest number of furnaces; there were a few in Kent, and a few in the Midland Counties, and along the Welsh borders. After the introduction of coke, the coal counties assumed a far greater importance in connection with iron than the woodland districts had done. Shropshire, Staffordshire, and South Wales became important; for some years past the greatest quantity of iron has been produced in South Wales; although Shropshire and Staffordshire have produced a superior metal. Scotland also has competed successfully in the production of this all-important metal.

"In whatever point of view the iron trade may be considered with regard to this country," says Mr. Mushet, "the advantages derived from its progress have been great; whether we consider it as having cleared the country of vast tracts of wood, affording at the same time an ample indemnification for the labour bestowed,—the consequent improvement in climate, and the spread of agriculture,—as having placed us at the head of the manufacturing countries of Europe,—as affording us at all times a plentiful supply for the construction of every species of machinery,—or, as having been a source of wealth to many individuals, and, at the same time, affording a competent recompense for the labour of a number of our fellow-creatures."

Section II.—Iron and its Compounds.

Iron is employed in the arts in three different states,—as *crude* or *cast-iron*, as *steel*, and as *wrought-iron*, the differences depending upon the relative amounts of carbon with which the metal is combined. Cast-iron contains a larger proportion of carbon than steel, and steel more than wrought or malleable iron, which ought to be quite free from carbon. In practice, however, this is never found to be the case, although the best malleable iron retains only a very minute portion of carbon. The iron of commerce is also contaminated with traces of silicium, sulphur, and phosphorus, the presence of which greatly influences the quality of the metal.

Pure iron may be obtained by introducing into a Hessian crucible 4 parts of fine iron wire cut small, and one part of black oxide of iron: this is to be covered with a mixture of white sand, lime, and carbonate of potash in the proportions used for glass making, or pulverised hard glass may itself be used, and a cover being closely applied, the crucible is to be subjected to an intense white heat. A button of pure metal is thus obtained, the traces of carbon and silicon present in the wire having been removed by the oxygen of the oxide, and combining with the vitreous flux form a slag. Pure metallic iron may also be obtained by passing hydrogen gas over one of the oxides of the metal contained in a tube of porcelain or hard glass heated to dull redness. The reduced metal will be in a spongy state, and by exposure to the air will absorb oxygen so greedily, as to take fire and become converted into a sesquioxide; but if the reduction be made at a high temperature, the particles cohere, and the metal does not ignite on exposure to the air.

Pure iron has a white or bluish grey colour, and acquires a brilliant surface by polishing. Its sp. gr. is 7·8, and its crystalline form is probably the cube. The texture of commercial iron varies according to its mode of preparation. Pure iron, which has been drawn out under the hammer in all directions, has a finely granular structure, but when rolled into long bars, as usually sent into the market, the texture is fibrous in the direction of the length. The fibres may be made evident by the fracture of a bar of iron under tension, or by acting upon it with dilute muriatic acid. Upon the perfection of this fibre much of the strength and value of iron depends, although by skilful management this *silky* character may be imparted to common varieties of the metal. The fibrous character is not, however, necessarily permanent, for after a time the metal has been found to assume a crystalline appearance, especially when subjected to constant vibration, as in the tension rods of suspension bridges, the axles of locomotives and of railway wagons, &c.[1]

Iron is the most tenacious of all the metals, a wire of $\frac{1}{30}$th inch in diameter bearing a weight of 60 lbs. It requires the strongest heat of a wind furnace to fuse it, but when combined with a small proportion of carbon it fuses at a much lower temperature. Before it becomes liquid, or when liquid before it becomes solid, iron passes through a soft or pasty condition, and hence crystallizes with difficulty; but when slowly cooled in large masses, indications of a cubical crystallization are obtained. At a full red-heat iron may be hammered into any form, and at a white heat, two pieces pressed or hammered together cohere: but in order that this operation, which is termed *welding*, may be successful, the surfaces must be in the metallic state, free from oxide; but as the oxygen of the air combines rapidly with iron heated to the welding point, it is usual to sprinkle a little sand over the heated metal, and this combining with the superficial film of oxide forms a fusible silicate, which forms a kind of varnish, and protects the metal from the air. On taking the bars out of the fire this silicate is by a rapid motion shaken off, and clean metallic surfaces can thus be brought into contact, or the silicate is forced out by the pressure applied in uniting them.

Iron, nickel, and cobalt, are the only metals which are evidently magnetic at ordinary temperatures. A piece of pure iron immediately becomes magnetic in the vicinity of a magnet, but it loses all magnetic properties as soon as the magnet is removed to a distance. Magnetism is developed in steel more slowly, but is retained more permanently; and a bar of steel rubbed by a magnet becomes itself a permanent magnet. The magnetic properties of iron diminish rapidly as the temperature rises; a mass of iron heated to redness has no action on the magnetic needle, but it regains its magnetic properties in cooling.

Iron does not oxidise in dry air, nor even in dry oxygen, at common temperatures; but in moist air it becomes covered with a scaly coating of black oxide or rust. The presence of carbonic acid in air greatly assists the operation, for the iron becoming changed into the carbonate of the protoxide absorbs a new portion of oxygen and is thus transformed into the hydrate of the peroxide of iron. The carbonic acid disengaged facilitates the oxidation of a new portion of metallic iron. When once iron has begun to rust at one point of its surface the rust spreads rapidly round this point in consequence of a galvanic action, which accelerates the oxidation. The small spot of rust forms the two elements of a voltaic pile, in which the iron is positive, and thus acquires for oxygen an affinity sufficiently strong to decompose the moisture of the air, hydrogen being set free. Rust also contains small portions of ammonia, the odour of which becomes evident by heating it with potash. Ammonia, which consists of hydrogen and nitrogen, is formed when these two elements come into contact in a liquid, in what is called the *nascent state*, that is, in the very act of separating from a body under decomposition. Now the moisture of the air containing a portion of air, and consequently a portion of nitrogen in solution, this moisture coming in contact with rust of iron, is decomposed, and the hydrogen and nitrogen which are set free at the same moment combine to form ammonia. The ammonia is retained by the peroxide of iron, which acts towards it as a weak acid would do.[2] Iron becomes soon rusty in pure water, but not in water containing minute portions of carbonate of soda or of potash. It is common now to preserve iron from rust by coating it with a thin layer of zinc, forming what is called *galvanised iron*, by a process explained under AMALGAM.

When iron is heated to redness, in contact with the air, a film of oxide forms, which falls off under

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(1) A few years ago Mr Charles Hood brought before the Institution of Civil Engineers some interesting facts respecting the conversion of fibrous into crystalline iron. According to him, the tough and fibrous character of wrought iron is entirely produced by art, and there is a constant tendency in such iron, under certain circumstances, to return to the crystallized state, which state is not necessarily dependent upon time for its development, but is determined by other causes, the chief of which is *vibration*. *Heat* within certain limits, though greatly assisting the rapidity of the change is certainly not essential to it, but *magnetism*, induced either by percussion or otherwise, is necessary to the change. It was shown by specimens, that in the same rod or bar of wrought iron, the crystallization is far more extensive in those parts most exposed to vibration. In the parts not so exposed, the texture remained fibrous.

(2) It was formerly supposed that when a steel or iron weapon, on which certain stains were observed, was heated in contact with potash, and emitted an ammoniacal odour, that this was sufficient evidence that such stains were produced by blood. Such evidence as this has been produced in criminal trials, but we now see that the exposure of an iron or steel blade to moist air is sufficient for the production of ammonia.

the hammer. When sparks are struck by the old-fashioned flint and steel, minute portions of the metal are struck off, and being heated by the friction of the flint the oxygen of the air seizes them, and they enter into combustion. If a piece of iron be struck with a flint over a sheet of white paper, it will soon be covered with small black grains capable of being attracted by the magnet, and which are in fact small globules of magnetic oxide of iron.

Four compounds of iron and oxygen are commonly described. The first is the *protoxide* (FeO) which acts as a powerful base completely neutralizing acids. It is seldom met with in a separate state, in consequence of its tendency to absorb oxygen and pass into the sesquioxide: its soluble salts have usually a delicate pale green colour, and a nauseous metallic taste. The *peroxide* (Fe^2O_3) is a feeble base, and may be prepared by precipitating a solution of persulphate or perchloride of iron by excess of ammonia, and washing, drying and igniting the yellowish brown hydrate thus produced. In the state of powder this oxide has a full red colour and is used as a pigment, for which purpose it is prepared by calcining the protosulphate, the tint varying with the temperature. This oxide dissolves in acids, forming a series of reddish salts. It is not acted on by the magnet. The *black oxide* (Fe_3O_4), also known as the *magnetic oxide* or the *lodestone*, does not form salts. *Ferric acid* (FeO_3) is prepared by heating a mixture of pure peroxide of iron with 4 parts of dry nitre; by subsequent treatment a solution of ferrate of potash is formed, which is not permanent, but when baryta is added a deep crimson insoluble ferrate of that base is formed, which is permanent.

By dissolving iron in hydrochloric acid, green crystals of *protochloride* ($Fe\,Cl$) may be formed, and by dissolving peroxide of iron in the same acid the red hydrated crystals of the sesquichloride (Fe_2Cl_3) may be produced. The *protiodide* (FeI), important in medicine, is formed by digesting iodine with water and metallic iron. There are several compounds of iron and sulphur. The *protosulphuret* (FeS) is formed by bringing a white hot bar of iron in contact with sulphur; but the usual method is to project into a red hot crucible a mixture of $2\frac{1}{2}$ parts of sulphur, and 4 parts of iron filings, excluding the air as much as possible. It is a blackish brittle substance attracted by the magnet. The *bisulphuret* (FeS_2) will be noticed among the ores of iron.

Compounds of iron with phosphorus, carbon and silicon exist; the *carburet* in cast-iron and steel, which it renders more fusible; the *silicon* compound is also found in cast-iron, which it probably renders brittle, as does also phosphorus, the presence of which is supposed to confer the property technically called *cold-short*, while the presence of sulphur renders iron *hot-short*.

Protosulphate of iron or *Green Vitriol*, $FeO,\ SO_3,+7\,HO$. This important salt may be obtained by dissolving iron in dilute sulphuric acid; but it is usually prepared on a large scale from iron pyrites, as will be noticed presently. Sulphate of iron slowly effloresces and becomes peroxidized in the air; it is soluble in about twice its weight of cold water. The *persulphate*, $Fe^2O_3,\ 3SO_3$, does not crystallize. The *protonitrate* $FeO,\ NO_5$, is not a very stable compound; the *pernitrate* is formed by pouring nitric acid, slightly diluted, upon iron; it is a deep red liquid used in dyeing. The *protocarbonate*, $Fe\,O,\ CO_2$, is formed by mixing solutions of the protosalts of iron and alkaline carbonates: it exists in the common *clay iron-stone*, and is often found in mineral waters.

SECTION III.—NATIVE AND METEORIC IRON, AND IRON ORES.

Native iron is of rare occurrence: it has been found in Saxony and elsewhere, forming the centres of stalactiform masses of brown hematite. These metallic kernels appear to have been produced by the decomposition of a portion of the oxide in which they are imbedded, a change which may have been brought about by electro-chemical agency.[1] Native iron is also produced by the spontaneous ignition of seams of coal in the neighbourhood of ferruginous deposits, producing small button ingots with a finely striated surface; they are very hard and fine grained, and are known by the name of *native steel*. Large masses of metallic iron exist in different parts of the world, and other similar masses have been observed to fall from the atmosphere. These *meteorites* differ in structure and composition from native iron: they always contain nickel, which is not found in the ores of iron, and they are covered with a kind of black siliceous varnish which protects them from the air; when this is removed the metal easily oxidises. Some of the masses of meteoric iron have been used by the inhabitants of the countries where they fell, in making knives, spears, and other instruments. There is a mass in South America estimated at 30,000 lbs. weight; one in Siberia, 1,600 lbs.; and one at Agram, in Croatia, which fell from the sky in 1750, in the presence of many witnesses. Numerous *aërolites* have at different times fallen from the atmosphere; they contain other substances in addition to iron. A stone, which fell at Château Renard on the 12th June, 1841, was found, by M. Dufrénoy, to contain per cent. silica, 30·13; alumina, 3·82; magnesia, 38·13; lime, 0·14; oxide of iron, 29·44; oxide of manganese, a trace; potash, 0·27; soda, 0·86; sulphur, 0·39; iron, 7·70; nickel, 1·55.

The ores of iron are very numerous, and we can only refer to a few of the most important in a metallurgical point of view.

One of the most universally diffused ores of iron is the *magnetic:* it occurs in granite, gneiss, mica-slate, clay-slate, syenite, hornblende, and chlorite; also in the limestone formations. Nearly all the

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(1) Mr. John Arthur Phillips, in his recently published *Manual of Metallurgy*,—an excellent guide-book to all persons interested in the chemistry of the metals,—explains this change by supposing, "that the whole or a portion of the iron formerly existed in the form of iron pyrites, (bisulphuret of iron,) which, becoming oxidised, not only produced a certain amount of the soluble sulphate of iron, but also generated by chemical action an electric current of sufficient power to precipitate a part of the iron in the metallic form."

Swedish iron is obtained from this ore. It is also abundant in the Island of Elba and in the United States of America. The primitive form of magnetic iron ore is a cube, but it often occurs in octahedrons and dodecahedrons. Its cleavage is often parallel to the faces of the octahedron. It is brittle, of an iron-black colour, and leaves a black streak. Density, 5·0 to 5·1. It is strongly attracted by the magnet, and sometimes possesses independent polarity. It contains iron, 71·78, and oxygen, 28·22; or peroxide of iron, 69, and protoxide, 31.

Specular iron; Red Hematite.—The crystals of this ore are generally complex modifications of the rhombohedron, of a dark steel-grey colour, opaque except in very thin laminæ, when they are transparent, and of a deep blood-red tinge. It leaves a reddish streak, and the density varies from 4·8 to 5·3. Pure specular iron consists solely of peroxide of iron.

There are several varieties of red iron ore. Fibrous iron, or *red hematite*, occurs in fibrous reniform masses. When there are no indications of columnar structure it is termed *compact*, and if mixed with argillaceous matter, it is known as *red ochre*. When specular iron has a foliated structure, it is called *micaceous*. Specular iron ore is also called *oligistic iron*, *iron glance*, and *rhombohedral iron*. *Juspery clay iron ore* is of a brownish red colour, with a large flat conchoidal fracture: when it occurs in small flattened grains it is called *lenticular clay iron*.

The purer varieties of this ore occur in the older formations: the argillaceous ores are usually met with in secondary rocks. The Island of Elba furnishes beautifully crystallized specimens: brilliant crystals are also found in the fissures of volcanic districts.

Red hematite is found in reniform masses in Cornwall, at Ulverstone in Lancashire, and other places. [See HEMATITE, Fig. 1117.] This ore, when ground to powder, is used as a pigment, and also for polishing metals.

The various ores of the peroxide are of great importance as a source of iron, although they do not yield so large a per-centage of metal as the magnetic oxide: the specular varieties are also somewhat refractory in the furnace; but by a proper mixture with other ores they yield an excellent iron.

Brown iron ore is, as its name implies, of a brownish colour, and it affords when crushed a yellow powder. Its density varies from 3·8 to 4·2. When pure it yields 55 per cent. of metallic iron. It is a hydrated peroxide, chiefly found in sedimentary rocks. Its forms are often pseudomorphic,[1] and these may be due to the decomposition of iron pyrites when it assumes the cube or octahedron. It also occurs in rhombohedrons from the substitution of carbonate of iron, as also in the moulds left by the decomposition of shells and madrepores, the shapes of which are assumed by the mineral. It also forms stalactites and hollow reniform masses. *Pea-iron* is one of its forms, found in the oolitic formations. When mixed with aluminous matter it acquires a soft texture, and is known as *yellow ochre*.

This ore is in some countries, France, for example, the most abundant source of iron; and when washed to separate the lighter impurities, it yields an excellent material for the manufacture of iron. But when beds of oolitic iron are found to alternate with calcareous deposits, the metal produced is *cold-short*, in consequence of the phosphorus derived from the organic matter of the chalk.

Iron pyrites, or bisulphuret of iron, FeS_2, containing, iron, 45·74 per cent., and sulphur, 54·26, crystallizes in the cubic system, frequently in pentagonal dodecahedrons, also in octahedrons and cubes more or less modified. The colour is bronze-yellow, with a metallic lustre; the streak, brownish-black; sp. gr. 4·8 to 5·1: it is brittle, and strikes fire with steel, whence the name *pyrites*. The cleavage is parallel to the faces of the cube and octahedron. It occurs in small cubical crystals, Fig. 1216, in veins, and in various slate-rocks and coal-fields, and in globular concretions in indurated clay and chalk. It also accompanies the ores of all the other metals, and in many cases replaces the remains of animal and vegetable forms. The crystals from Elba are very fine: very large cubes are also obtained from Cornwall, and large perfect octahedrons from Sweden. It is also found in many of the coal-fields, where, by its oxidation and conversion into sulphate of iron, the temperature is in some cases so much raised as to ignite the coal.

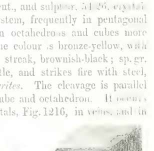

Fig. 1216.

Iron pyrites is not used as a source of metallic iron; but is frequently employed as a source of sulphur in the manufacture of alum and sulphuric acid. [See ALUM—SULPHURIC ACID.]

White-iron pyrites has the same composition as the above, but crystallizes in forms derived from the right rhombic prism. It often occurs in radiated crystallized masses, called *cockscomb pyrites*. It occurs in most of our mineral districts. There is also a *magnetic iron pyrites*, and an *arsenical iron pyrites*.

We must also refer to *chrome-iron*, which occurs so abundantly in the Shetland Islands, and is used for making chromate and bichromate of potash; and to *tungstate of iron*—*Wolfram*—which has been lately employed for making tungstate of lead, to be used as a pigment instead of the white-lead now in use.

The ore from which the greater portion of the iron manufactured in this country is obtained, is the *carbonate*. It occurs in rhombohedrons and six-sided prisms, resembling carbonate of lime: also in globular concretions, or lenticular masses. When pure, it consists of protoxide of iron 61·37 per cent., and carbonic acid 38·63. It is known by the various names of *Siderite*, *Sparry iron*, *Spathose iron*, *Brown spar*, &c. Sparry-carbonate of iron, Fig. 1217, often accompanies other metallic ores, such as those of lead or copper. In Styria and Carinthia the beds occur in gneiss; in the Hartz, in grey-wacke; but the English deposits are confined to the coal-formation: it usually occurs in horizontal strata, subject, however, to the same inclination as the other strata which it accompanies. It is generally found imbedded in schistous clay, more or less compact, which moulders away when exposed to the air. Hence its well-known name of *clay ironstone*. It is of grey, blue, brown, or black colours, with sp. gr. from 2·8 to 3·5, and hardness from 3·5 to 4·5. It occurs, as already stated, chiefly in slate, clay, or marls, in layers or nodular masses, often containing fossil plants, or other organic bodies, which seem to have attracted the carbonate of iron. In these nodules, crystals of siderite, calc-spar, celestine, barytes, quartz, pyrites, blende, and galena often occur. This variety is found occasionally in the transition rocks, but especially in the coal formation of Britain, Belgium, and Silesia in vast abundance. It is more rare in the oolite and chalk in Northern Germany, and England; and in the brown coal of Radnitz in Bohemia, and other places, frequently forms petrifactions of wood. The ironstone is met with under two different forms: in regularly connected strata, called *bands*, and in strata of detached stone, formed in distinct masses, from the size of a small bullet to that of lumps of several hundred pounds weight. What is called *black-band*, or *carbonaceous* ironstone, is also a carbonate of iron, containing carbonaceous matter in addition to the ordinary earthy substances found in all argillaceous ironstones. The difference between black-band and clay ironstone will be seen from the analysis of varieties of the two.

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[1] A *pseudomorphous* crystal, (from [illegible], false, and [illegible], form,) is one that has a form which is not known in the species to which the substance belongs. There are many causes for pseudomorphism, as when a cavity left empty by a decomposed crystal, is refilled by another species by infiltration, and the new mineral assumes the external form of the crystal removed. Crystals may also be incrusted over by other minerals.

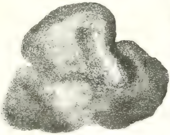
Fig. 1217.

The carbonaceous matter in the black-band varieties, Nos. 1 to 5, materially assists in the reduction of the ores. Mr. Mushet says, in referring to this ore, that instead of 20, 25 or 30 cwt. of limestone formerly used to make a ton of iron, the black band only requires 6, 7, or 8 cwt. This arises from the extreme richness of the ore when roasted, and from the small quantity of earthy matter contained in it, which renders the operation of smelting the black-band with hot blast more like the melting of iron than the smelting of an ore. When properly roasted, its richness ranges from 60 to 70 per cwt., so that little more than 1½ ton is required to make a ton of pig-iron; and as 1 ton of coal will smelt 1 ton of roasted ore, it is evident that when the black band is used alone 35 cwt. of raw coal will produce 1 ton of good grey pig-iron.

The following is the composition of the celebrated *Black-band*, (Nos. 1 to 5,) and other argillaceous iron ores of Scotland and Wales.

	Carbonate of iron	Carbonaceous matter	Earthy matter	Metallic iron in carbonate	
1.	70·0	23·0	7·0[1]	33·7	Black Band, Lanarkshire.
2.	51·04	22·16	26·80	24·6	Cwan Avon bed, S. Wales.
3.	63·9	10·0	26·1	30·7	Maesteg Valley, Upper bed, Upper division.
4.	79·9	6·6	13·5	38·5	Ditto, Lower division.
5.	79·5	16·4	4·1	38·4	Beaufort, Ponty pool, 4 inch band.
6	86·0	...	14·0	41·5	Ystradgunlas, Upper vein.
7.	72·4	...	27·6	34·9	Ditto, another bed.
8.	75·4	...	24·6	36·4	Pendaren, Red vein.
9	60·9	...	39·1	29·4	Aberfergwm, Nodules.
10	55·5	...	44·5	26·6	Pendaren, Jack vein.

The different kinds of ironstone are known by various local names, many of which are given by Mr. S. H. Blackwell, in his catalogue of the series of iron ores contributed by him to the Exhibition of 1851. From this list we gather the following particulars respecting the iron-making districts of England and Wales. Details of later date will be given in the APPENDIX.

South Wales is the most important iron-making district in the world. Its coal-field extends over an area of upwards of 800 miles, and from its extent, and the varied character of its numerous beds of coal, and its measures of ironstone and black-band, it may be considered as the most important of all our coal-fields. The number of furnaces now in blast is 143, averaging about 100 tons of iron each per week: or a gross annual production of 700,000 tons, and requiring 2,000,000 tons of ironstone, which is principally furnished from this coal-field. The annual production of coal is estimated at from 5 to 6 million tons. In 1796, the annual production of iron in South Wales was 34,011 tons; and in 1823, 182,325 tons; since which time the production has been more than trebled. In 1851 it was 750,000 tons.

The production of iron in North Wales is very limited: the coal-seams are thin, but good in quality, and the ironstones, although lean, furnish very good iron.

In Shropshire, the annual production of iron is about 90,000 tons. The quality is very good. This field was one of the first important iron-making districts of the kingdom; but from its limited extent the production has not increased for a long period.

The Dudley division of the South Staffordshire and Worcestershire coal-field is principally celebrated for its ten-yard or thick coal. When undisturbed by faults, and of average quality, this bed of coal, with the associated thin coals and ironstones, is worth at

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(1) This includes silica, alumina, and a trace of lime.

least 1,000*l*. per acre. The quality of the iron is very superior. The *Gubbin* and *White* ironstones are the principal ironstones of this district. The Gubbin measures average about 1,500 tons per acre. the White ironstone varies both in quantity and richness; it yields from 1,000 to occasionally 3,000 tons per acre; but 1,500 tons may be taken as about the average.

In the Wolverhampton district the iron occupies a position in the general coal series below the thick coal of the Dudley district, and attains a much greater thickness and importance than at Dudley. The ironstones are all of good quality, averaging from 30 to 35 per cent. of metal. From the low cost at which they are generally raised, the number and variety of the measures of coal and ironstone contained in so small a space of ground, and the superior quality of the iron produced, the Wolverhampton division of the South Staffordshire coal field may be considered as one of the most important, in proportion to its area, of any of our iron-making districts.

The annual production of iron in South Staffordshire and Worcestershire is nearly 600,000 tons. It may be regarded as the second iron-making district in the kingdom; for although the production of pig-iron in Scotland is equal to that of this district, yet it far surpasses Scotland in the manufacture of wrought-iron; while the superior quality produced also gives it pre-eminence over that of Wales.

North Staffordshire produces only about 55,000 tons of iron, but it is of great importance from the vast quantities of ironstone which it contains, and the large quantities which it sends to the South Staffordshire and the North Welsh iron districts. No other known coal-field contains anything like an equal number and extent of iron-measures. In consequence of so large a proportion of the cheapest worked ironstone measures being black-band or carbonaceous, and also from the inferior quality of its coals, the iron of this district is inferior.

In the northern district of Yorkshire the annual production of iron is about 25,000 tons, and the quality very superior. The southern district produces about 20,000 tons.

The annual production in Derbyshire is about 60,000 tons. Many of the beds of ironstone lie in such a thickness of measure as only to be workable to advantage by open-work or bell-pits, in which case the produce per acre is often very large; in one case it is 6,000, and in another 8,000 tons per acre.

Northumberland, Cumberland, and Durham produce about 90,000 tons per annum. The iron-works are increasing in importance, the cost of fuel being so low, as to admit of ores being brought from many different localities. The black bands of Scotland and of Haydon Bridge, the brown hematites and white carbonates of Alston and Weardale, and the argillaceous ironstones of the lias of Whitby and Middlesborough, are all used in the iron-works of this district. The brown hematites are found associated in very large masses with the lead veins of this district, and they sometimes occur in distinct and regular beds. They contain from 20 to 40 per cent of iron. In some cases they exist as *riders* to the vein; in others, they form its entire thickness, which is occasionally 20, 30, and even 50 yards.

The production of iron in the Lancashire and West Cumberland district is very limited, it being confined to the Cleator works, and one or two small charcoal works in the Ulverstone district. The quality of the latter, charcoal being used as the fuel, is very superior, and the produce commands the highest price, as it combines with the fluidity of cast iron a certain malleability, especially after careful annealing. The iron of the Cleator works is smelted with coal, and is of superior quality, although not equal to the other. The ore both of the Whitehaven and the Ulverstone and Furness districts is extensively raised for shipment to the iron works of Yorkshire, Staffordshire, and North and South Wales. In quality these ores may be considered as the finest in the kingdom; they contain from 60 to 65 per cent. of iron. They are found both as veins traversing the beds of the mountain limestone formation, transversely to the lines of stratification, and also as beds more or less regular. The former is the general character of the Ulverstone and Furness ores; while at Whitehaven there are, at least, two beds of irregular thickness, but with clearly defined floors and roofs, and often subdivided by regular partings. These beds are occasionally 20 or 30 feet thick. They lie beneath and close to the coal measures, which both furnish the necessary fuel, and also important beds of argillaceous ironstone for admixture.

The Forest of Dean produces every year about 30,000 tons of iron. The ores are carboniferous or mountain limestone ores lying beneath the coal measures, which are not here productive of argillaceous ironstones, as in the other principal coal-fields of the kingdom. There is also a bed of ore in the millstone-grit measures. The limestone ore is arranged rather in a series of chambers than in a regular bed. These chambers are in some places of great extent, and contain many thousand tons of ore, which is generally raised at low cost, no timbering or supports for the roof being required. The iron made from this ore is of a red short nature, and is especially celebrated for the manufacture of tin plates. It commands a high price, and is extensively shipped to South Wales. It yields from 30 to 40 per cent of iron.

The micaceous iron ores, and the magnetic oxides of Dartmoor, &c., are only just beginning to be known. They produce a superior iron, adapted to the manufacture of the finest steel.

In the Island of Anglesea, Tremadoc, Carnarvon, and other localities round the North Welsh coast, are ores of inferior quality, but lying in large masses; they can be raised at trifling expense.

In some parts of Somersetshire, Gloucestershire, &c. hematitic conglomerates are found at the base of the new red sandstone. Their character as workable ores is very variable, being mixed up with so much extraneous material as to be almost worthless; but in some cases they exist in regular beds, and contain so large a portion of hematite as to be of importance.

The clay ironstones of the lias are only just beginning to be added to our iron-making resources. They furnish an example of the unexpected development of natural wealth, arising from the facilities afforded by railroads. Ironstone is raised at a cheap rate along the outcrop of the beds, on the coast from Whitby to Scarborough. An important bed has lately been opened at Middlesborough. Mr. Blackwell has recently shown the vast extent and importance of the silicious ironstone from the oolite near Northampton.

The greensand of Sussex, which, in consequence of the exhaustion of our forests, has long ceased to yield ironstone to our furnaces, may, in consequence of the facilities of transit offered by railroads, again be called upon to yield supplies of this important ore. Scotland in the year 1851 produced 775,000 tons of iron.[1]

SECTION IV.—PREPARATION OF THE ORE AND FUEL FOR SMELTING.

Iron ores are not sufficiently valuable to allow of the crushing, stamping, washing, and other processes which precede the reduction of copper, tin, and other ores. They are usually roasted for the purpose of expelling water and carbonic acid, and producing that porous condition which is favourable to the smelting process. The argillaceous carbonate, or clay ironstone of the coal measures, which, as already stated, is the chief source of the iron of this country, and produces from 30 to 33 per cent. of pig iron, loses by roasting from 25 to 30 parts in every 100. The loss consists chiefly of water and carbonic acid.

The usual method of roasting the ironstone is in heaps, for which purpose a piece of ground is levelled and covered with a layer of coal, from 6 to 8 inches thick. The pieces of ironstone, as near the same size as possible, are arranged upon this, to the height of about 2 feet. This surface is levelled by introducing small pieces of ironstone in the spaces left by the larger pieces. Upon this small coals are cast in a layer of about 2 inches. Ironstone is then piled up so as to form a wedge-shaped heap, and the hole is lastly covered with small coal. The usual height of such a heap is 6 or 7 feet, and its breadth at the bottom from 15 to 20 feet. The pile is lighted by applying coals to the ground stratum at the windward end, and after having burned to a certain distance, the pile is prolonged in the opposite direction. The fire creeps slowly along, gradually igniting the whole heap from the bottom to the top. When the coals are all burnt out, the pile gradually cools, and in about a month from the commencement of the operation the ore is fit for the furnace.

The roasting of the ore is also frequently carried on in furnaces resembling lime-kilns. In a hilly district, such as that of Colebrook Dale, they are built of the form shown in Fig. 1218, by the side of a hill, so that the mouth of the furnaces may be on a level with the mouth of the pit, and the ore, as it is raised, is wheeled along a railroad, and emptied into them. The kilns are entirely filled with ironstone, except a stratum of coals at the bottom; and when sufficiently roasted the register is closed, and the whole allowed to cool.

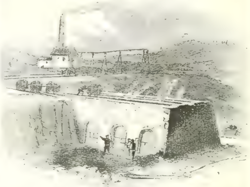

Fig. 1218. ROASTING IN KILNS. (Colebrook Dale.)

Black-band ironstone contains a considerable proportion of bitumen, in which case, when once ignited, it will continue to burn for a long time. Those ores which do not contain any combustible matter require during the roasting a small addition of coal dust. Hence the proportion of coal required for calcining clay ironstone varies from 5 to 20 per cent, depending on the proportion of bituminous matter.

The coal used in the reduction of the ore is, to a great extent, *coked*. This operation is performed upon a flat oblong or circular surface, called a *hearth*, which is prepared by beating and puddling over with clay. The coal is arranged on the hearth in pieces, regularly inclining to each other, each piece being placed on its sharpest angle, so that as small a surface as possible may touch the ground; by which means spaces are preserved for the admission of air, and for the swelling of the coals under the heat. In building the pile, a number of flue holes are made,

Fig. 1219. COKE HEAPS NEAR DUDLEY.

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[1] The [illegible] analyses of iron ores [illegible] fully stated in Mr Phillips's Manual of Metallurgy.

extending along the ground, and terminating in vertical shafts in the centre. The heap is ignited by putting burning fuel into these vents, which are then stopped by small pieces of coal, to prevent the fire from ascending, and to cause it to creep along the bottom, where the draught is freest. When the fires of the different vents meet, the combustion gradually rises and bursts forth on all sides. Soon after the smoke has ceased, the fire is covered up with the dust and ashes of former burnings, beginning at the base and gradually heaping it up to the top. From 40 to 100 tons of coal are coked in one hearth. The time for coking depends upon the quality of the coal and the state of the weather. The combustion of the volatile matters may be complete, and the heap be covered over, in from 50 to 70 hours, but it will not be cool enough for drawing under 12 or 14 days. Mr. Mushet found the loss of weight in coking to be as follows:—

2,240 lbs.	Yields.	Loss.
of free coals	700 lbs.	1,540 lbs.
of splint and free coal mixed .	840 ,,	1,400 ,,
of splint slightly mixed . .	1,000 ,,	1,240 ,,
of pure splint	1,100 ,,	1,140 ,,

It is calculated that in Staffordshire from 3½ to 4 tons of coal, including that employed for roasting the ore, are required for the production of 1 ton of cast iron. In Wales, where the coal produces a larger per-centage of coke, 3 tons of coal suffice for the manufacture of 1 ton of iron.

SECTION V.—THEORY AND PRACTICE OF IRON-SMELTING.

It has been already stated that oxide of iron is easily reduced, if a stream of hydrogen be passed over it at a red heat. A stream of carbonic oxide would be equally efficacious. But the reduction of these oxides, however easy in theory, is difficult in practice, because the particles of iron, as they are reduced, become so intimately mixed with the gangue, that they cannot combine or weld together. If the gangue were fusible at a moderate heat, it would be sufficient to raise the ore to the temperature at which the stony matters fuse, and then subject the metallic sponge thus formed to the blows of a heavy hammer, or to the compressing force of powerful rollers. The particles of iron would coalesce, and the gangue be squeezed out in the form of scoriæ or slag. If, however, the gangue were refractory, it would only fuse at the temperature at which the iron in contact with the fuel became converted into *cast* instead of *malleable* iron, which would otherwise be obtained. The ordinary gangue of iron is clay or quartz, two substances infusible by the heat of a blast furnace. In order to determine their fusion, two methods are adopted. If the ore be very rich, and it be required to produce malleable iron from it by a direct method, the ore is heated in contact with carbon: the gangue combines with a portion of the oxide of iron, forming a very fusible double silicate of alumina, and protoxide of iron; while the other portion of the iron is reduced, and all that is necessary is to pass the spongy mass under a hammer to expel the slag, and bring about the aggregation of the particles. But in this operation a portion of the oxide of iron is lost, varying in amount with that of the gangue. This *Catalan* process, as it is called, produces an excellent iron, well adapted to the making of steel; it is still adopted in some places where wood is abundant for making charcoal, as in the Pyrenees, in Corsica, and some parts of Spain; but unless the ore be a very rich one, this process, wasteful alike of fuel and of ore, cannot be adopted. In the poorer ores, where the object is to extract as much of the iron as possible, the silicate of alumina must be rendered fusible by giving it some other base than oxide of iron, and for this purpose the most economical is lime. But since the double silicate of alumina and lime is much less fusible than the silicate of alumina and iron, a very elevated temperature must be employed; the iron combines with carbon, and forms crude or cast iron, which is found in a state of fusion below the fused silicate or slag. By this method, which is essentially the *English* one, nearly all the iron at present manufactured is procured. The iron ore, with a proper proportion of carbonate of lime as the flux, and coke or coal as the fuel, is raised to a very high temperature in an apparatus called a *Blast furnace*, a section of which is represented in Fig. 1226, while Fig. 1227, will convey a very good idea of its external appearance.

The blast furnace consists of two truncated cones A, B, united at their bases. The upper part, called the *cone* or *body*, is formed by an interior lining or *shirt* of

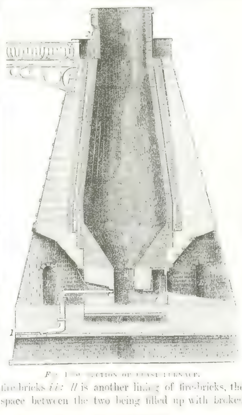


Fig. 1226.—SECTION OF BLAST FURNACE.

fire-bricks *i i*: *l l* is another lining of fire-bricks, the space between the two being filled up with broken scoriæ or refractory sand. The outer casing of fire bricks *ll*, is supported by a thick wall of masonry or brick, and this is strongly bound on the outside by stout iron bands connected by long vertical bars, whereby great strength and solidity is given to the building. The exterior casing is also traversed by numerous small channels, to allow of the escape of moisture from the masonry or brick-work, since any pent-up steam might lead to the destruction of the furnace. At the top of the furnace is an opening G, called the *throat* or *tunnel-hole*, and above this is the chimney F, in which are openings, which, with the throat, are used for pouring in the charge of fuel, ore and flux. The lower cone B, called the *boshes*, is formed of fire-brick or fire-stone, and requires the greatest care in its construction, for upon its durability depends the continued operation of the furnace. To prevent the formation of an acute angle at the junction of the two cones, forming the body of the boshes, the edges are slightly rounded off by the introduction of a narrow belt, whereby a space is formed called the *belly*. The lowest division E, called the *hearth*, is nearly quadrangular in form: it is constructed with large slabs of refractory sandstone cemented with fireclay. It is somewhat smaller at the bottom than at the point where it meets the boshes, and its angles are gradually rounded off. The bottom of the furnace is formed of a large fire-stone, supported by a mass of masonry in which are various channels H, left open for the escape of moisture from the brickwork; and to keep the whole structure dry; the foundations are traversed by two large arched vaults V, V, which intersect each other just below the axis of the furnace. Three of the sides of the hearth are continued down to the large fire-stone: the fourth side, D, is carried down to a certain distance, where it is supported by strong cast-iron bearers let into the masonry of the walls, which also support a heavy block of sandstone called the *tymp*. Below this, at a distance of 5 or 6 inches and a little in advance of it, is the *dam-stone*, *d*, prismatic in form, secured on its outer side by a piece of cast iron called the *dam-plate*. The part of the furnace below the tymp is called the *crucible;* and in it is collected the fused metal reduced by the operations of the furnace. The three continuous faces of the hearth are perforated a little above the level of the tymp with holes *o o*, for receiving the nozzles of tuyeres, which convey the blast from the blowing machine to the furnace. The vaulted galleries L L (corresponding to K K in Fig. 1221), allow the workmen to pass from one tuyere to another without loss of time.

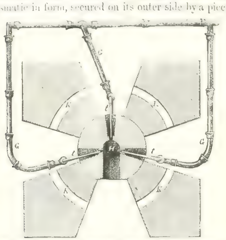


Fig. 1221. HORIZONTAL SECTION, SHOWING THE TUYERES.

Fig. 1221, is a horizontal section of the furnace at the height of the tuyeres *t*, showing also their arrangement and that of the pipes G which connect them with the blowing-machine. Each pipe is furnished with a valve worked by a screw on the outside, by which the quantity of air admitted into the furnace is regulated. The tuyeres, which are built into the hearth, are conical tubes of cast-iron, and to prevent them from being melted by the intense heat of the furnace they are made hollow, and a current of cold water allowed to circulate through them in the direction of the arrows, Fig. 1222, one pipe bringing the cold water and the other discharging it after it has been heated. Within these tuyeres are placed the nozzles of the blast pipes; and it will be seen by reference to Fig. 1221, that by setting the tuyeres not opposite each other but somewhat inclined, the blasts do not meet each other, but each one operates upon a different part of the hearth H.

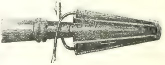


Fig. 1222.

The blowing-machine in common use is shown in section in Fig. 1223. It consists of a large cylinder of cast-iron A, furnished with a piston P, fitting air-tight, the piston rod R passing through a stuffing-box at the top, and usually connected by a parallel adjustment to the oscillating beam of a steam engine. The cylinder is closed at the two extremities, but there are two lateral openings *r r‴* communicating with the outer air, and two other openings *r′ r″* communicating with a side chamber B, also of cast-iron. The operation of this machine is as follows:—Supposing the piston to be descending from the top to the bottom of the cylinder, it will condense the air below it; this will force open the valve *r′* and escape into the chamber B. By this act the valve *r‴* will be more firmly closed, since it is so hung that it can only open from without inwards. While this operation is proceeding, the air above the piston being greatly rarefied,

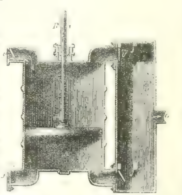
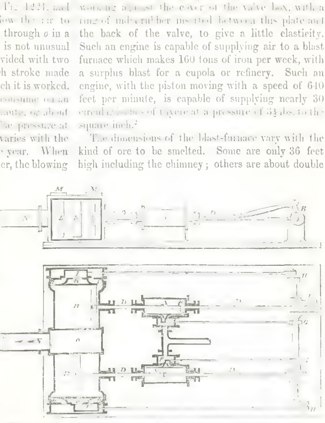


Fig. 1223. SECTION OF BLOWING MACHINE.

the denser air on the outside forces open the valve *v*, and rushes in; the valve *v″* cannot open during this act, because it is hung so as to open only from A into B, not from B into A. Supposing the piston to have arrived at the bottom of the cylinder and to be ascending, the air above it becomes condensed and passes through *v″*, into B, while *v* becomes firmly closed; at the same time fresh air rushes in below the piston through *v‴*, and *v′* is closed. From B, the air passes through *o*, to the pipes G G, Fig. 1221, and the use of the chamber B is, to allow the air to equalize itself so that it may proceed through *o* in a stream of tolerably equal density. It is not unusual for each blowing machine to be provided with two cylinders, which act alternately at each stroke made by the beam of the steam engine by which it is worked. Some of the large Welsh furnaces[1] consume on an average 3,600 cubic feet of air per minute, or about *nine tons weight of air per hour*. The pressure at which the air is sent into the hearth varies with the nature of the fuel and the season of the year. When the air is rarefied by the heat of summer, the blowing machine must be exerted more than in winter, in order to supply the furnace with the same amount of oxygen. Less pressure is required with a light and easily combustible fuel, such as charcoal, than with a dense coke. In the former case the pressure may not exceed ½ lb. on the square inch; in the latter, the average is about 2½ or 3 lbs.

The objection to this form of blowing-engine is its great size, and the small velocity with which the air is driven, this being no higher than that of water passing through an ordinary pump. When the engine is not driven by water power, but by steam, there is no reason why as great a velocity should not be imparted to it, as a high-pressure locomotive power is capable of supplying. With these views Mr. Archibald Slate of Dudley has contrived a blowing engine, the construction of which will be understood by referring to Figs. 1224, 1225, which represent an elevation and plan thereof. A A, are the steam cylinders, each 10 inches in diameter and with 2 feet stroke, and B B the blowing cylinders, 30 inches in diameter and 2 feet stroke, with their pistons C fixed on the same piston rods D, which are connected to two cranks E, fixed at right angles to each other on the same shaft. The slide valves F of the steam cylinders are worked by the eccentrics G, on the cranked shaft, and the cranks H, at the outer ends of the same shaft, work the slide valves I of the blowing cylinders. The centre port K passes downwards to an external opening for the admission of the air, and the discharge ports L L, deliver into the passages M, on the top of the cylinder, which communicate with the air main N, by the chest O, formed between the cylinders. The piston of the blowing engine is made without any packing, it being a light hollow cast iron piston turned to an easy fit. The slide valve of the blowing cylinder has a packing plate at the back, working against the cover of the valve box, with a ring of india-rubber inserted between this plate and the back of the valve, to give a little elasticity. Such an engine is capable of supplying air to a blast furnace which makes 160 tons of iron per week, with a surplus blast for a cupola or refinery. Such an engine, with the piston moving with a speed of 640 feet per minute, is capable of supplying nearly 30 circular inches of tuyere at a pressure of 3½ lbs. to the square inch.[2]



Figs. 1224, 1225. ELEVATION AND PLAN OF SLATE'S HIGH PRESSURE BLOWING ENGINE.

The dimensions of the blast-furnace vary with the kind of ore to be smelted. Some are only 36 feet high including the chimney; others are about double that height; but the usual height is from 45 to 50 feet without the chimney, which is 8 or 10 feet more. In such a furnace the crucible will be about 6½ feet high, and 2½ feet square at the top; the boshes 8 feet high, and 12 feet in diameter at the top; the cavity of the furnace is about 30 feet high; the chimney 8 feet high, and widened to 16 feet to allow the charge to be easily tossed in. The form of furnace shown in Fig 1220 is adapted to the hot-blast, cold-blast furnaces being narrower at the top. Some of the largest furnaces are in South Wales, in which the diameter at the boshes, or widest part, is from 15 to 18 feet. These have a capacity of 7,000 cubic feet, and contain at least 150 tons of ignited materials.

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[1] The dimensions of the great blowing machine at one of the largest of the Welsh ironworks are as follows:—diameter [illegible] feet [illegible] inches; length [illegible] feet [illegible] inches. The piston has a stroke of 8 feet, and makes 13 strokes in a minute. Allowing [illegible] per cent. for loss by leakage, we have 12,[illegible] cubic feet of air expended per minute.

[2] The speed of [illegible] per minute is about [illegible]. In 18[illegible], Mr. Slate erected at the Woodside Iron Works, near Dudley, a 15-inch blowing cylinder, worked by a steam engine with a cylinder 14 inches in diameter. The [illegible], the boiler 27 feet long and 4 feet in diameter. On the main air pipe were placed 4 tuyeres, 2 of them 2½ inches, the others 2 inches diameter. The engine being run up to its full velocity, reached 15 strokes per minute, at which rate the density of the air issuing from the 4 tuyeres was [illegible] per inch, [illegible] on account of the great regularity of the blast. With an adjusting expansive valve fitted to this engine, a full complement of blast was thrown into one furnace, viz. [illegible] cubic feet of air per minute; the pressure of the air in the main close upon the engine was a little over 3 lbs. to the inch; at the tuyeres on the furnace it was rather under, the loss [illegible] friction and leakage on account of the tortuous character and length of the main, which exceeded 300 feet.

Much care is required in raising a new furnace to the temperature necessary for the smelting of iron. A temporary fire-place is first erected at the lower part, to which the whole cavity of the furnace is made to act as a chimney, so that when the fire is lighted, the draught is violent, and much heat is carried up. The fire is kept burning for about three weeks, at the end of which time the furnace is sufficiently dry to receive a charge of coke. The temporary fire-place is then removed, and other preparations are made for the purpose. A quantity of ignited coke is thrown in, and this is gradually increased until the whole cavity is filled. The quantity required by a furnace of the average size is about 99,000 lbs., the splint coal for which would weigh 198,000 lbs. When the furnace has been sufficiently heated by coke, proportionate charges of coke, ironstone, and blast-furnace cinders are added. At first the ironstone bears only a small proportion to the weight of the coke, but is afterwards increased to the full burden. The filling is continued regularly, and when the top of the furnace has acquired a considerable degree of heat, the blast is introduced. Before admitting the blast, the dam-stone and dam-plate are laid. On the top of the plate is a slight depression, curved outwards, to allow the slag to flow off in a connected stream, as it tends to surmount the level of the dam. From the dam-plate to the level of the floor, a declivity of brick-work is erected, down which the slag flows. The fauld is stopped up with sand, and the furnace bottom covered with powdered lime or charcoal dust. Ignited coke is then allowed to fall down, and is brought forward with iron bars nearly to a level with the dam. The tuyere holes are opened, and lined with a soft mixture of fine clay and loam. The blast is first introduced through a small discharge-pipe, and afterwards a larger one is used. In about 2 hours after blowing, a considerable quantity of lava will be accumulated; this is admitted to all parts of the hearth, and glazes the surfaces of the fire-stone. It then rises to a level with the notch in the dam-plate, and flows over. When the metal has risen nearly to a level with the dam, it is let out by cutting away the hardened loam of the fauld, and conveyed by a channel made in the sand in front of the furnace, to the place where it is cast into pigs, as will be noticed more particularly hereafter. In 6 days from the commencement of blowing, the furnace will have wrought itself clear, at which time the charge will be in the following proportions:—400 lbs. of coke, 336 lbs. of clay ironstone, and 100 lbs. of limestone. This charge is thrown into the furnace every hour. In the hilly district of Colebrook Dale, the blast-furnaces are built by the side of a hill, on the summit of which the charge is prepared, and tossed into the furnace mouth, as shown in Fig. 1226. Near Dudley the charge is in some cases moved by steam power up an inclined plane, as represented in Fig. 1227; in other cases a mechanical lift is employed.

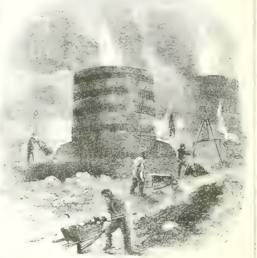

Fig. 1226. [illegible] OF BLAST-FURNACES. (*Colebrook Dale.*)

The action of these three substances upon each other, leading to the production of a vitreous slag, and metallic iron, has already been stated. The chemical changes by which these apparently simple results are brought about, are somewhat complicated The charge having been thrown in at the top of the furnace, gradually descends until it reaches the upper part of the boshes. In the cone the heat is not very great: near the boshes it is considerable, and in the hearth it is at its maximum, for here the oxygen of the blast meets the fuel, and produces the

Fig. 1227. BLAST FURNACES NEAR DUDLEY.

most vivid combustion. At about the middle of the boshes, the heat is much diminished, for the oxygen having been converted into carbonic acid, this gas and the nitrogen of the air of the blast part with a portion of their heat to the fuel and the mineral at the lower part of the cone. Here the carbonic acid, in contact with the heated fuel, combines with an equivalent of carbon, and becomes converted into carbonic oxide, with a great expansion of volume, and consequently a great absorption of heat, so that while the boshes are at a white heat, the base of the cone is only at a red. As the carbonic oxide, at a high temperature, comes in contact with the oxide of iron, it reduces it to a metallic state, and becomes converted into carbonic acid. This acid gas is also formed by the conversion of the limestone into caustic lime, so that the gases which escape by the throat of the furnace consist of nitrogen, carbonic oxide, and carbonic acid. There is also a portion of hydrogen and carburetted hydrogen, arising from the dry distillation of the fuel in the upper part of the cone, for the coal is never so thoroughly coked as to have parted with all its gases. A certain amount of moisture enters by the tuyeres, and its decomposition increases the quantity of carbonic oxide and hydrogen. Hence it will be seen that a vast amount of inflammable gaseous matter must be constantly pouring from the blast-furnace all the time that it is in action, producing a great body of flame and smoke by night, and lighting up the country for miles around.

The chemical changes which go on in different parts of the furnace, have been tested by collecting the gases at various distances below the throat or tunnel-hole, by passing a wrought-iron pipe to the depth at which it was required to examine the products of combustion. To the upper extremity of this tube was connected a leaden pipe, by which the gases were conducted to a place suited for their analysis. Near the throat of the furnace, the hygroscopic water is driven off from the charge. When it has sunk to the distance of 10 or 12 feet from the surface, the combined water of the hydrated oxide of iron begins to be expelled, and a little lower down, the carbonic acid, both of the ore and of the flux, is partly set free, and a portion of the oxide of iron becomes reduced to the metallic state. In the lower part of the cone, and at the commencement of the boshes, the reduction is completed, and the rest of the carbonic acid liberated. At the lower part of the boshes, where the temperature is very high, the lime of the flux and the ash of the fuel combine with the silica to form various double silicates, which afterwards form a fusible slag. Here also the iron is exposed in a slightly oxidising atmosphere to a very high temperature in the presence of carbon, a portion of which substance combining with the metal, converts it into *cast-iron*. The presence of the iron and the carbon also serves to reduce a portion of the silica, the silicium combines with the iron, and the oxygen of the silica with the carbon. When the charge thus modified arrives at the upper part of the hearth, the intense heat, caused by the action of the blast upon what remains of the fuel, completely fuses both the iron and the silicates, and they pour down into the crucible beneath. The construction of the hearth allows the melted products to fall rapidly through the blast, and this is quite necessary, for the oxidising influence of the vast body of air poured into this part of the furnace is such, that it would speedily convert the reduced metal to an oxide, which would be rapidly absorbed by the slag, and thus occasion great loss. But on reaching the crucible, the fused products arrange themselves in the order of their density. The iron occupying the lowest part, and being covered by the silicates, is completely protected from all oxidising influence. The silicates or slag occupy a volume five or six times greater than that of the iron, so that as it rises to the level of the dam-plate, it flows over, and passes down the inclined plane to the ground, and when cold is removed by means of pointed iron levers. At some works the slag is made to flow into iron waggons, whereby it is moulded into large blocks. These waggons run on a railway, so as to admit of being easily wheeled off. The iron slowly accumulates in the crucible, and in the course of 8, 12 or more hours, according to the construction of the furnace, the furnace is *tapped*, and the liquid metal drawn off. For this purpose the plug of refractory clay, which closes a hole in the bottom of the crucible, is pierced with a long bar. But before tapping, the men prepare for the reception of the liquid metal a number of moulds in the sand which composes the floor of the workshop. For this purpose blocks of wood are buried, which on being taken up leave a number of parallel trenches. These are connected by a channel at right angles to them, and communicate with the hole at the bottom of the crucible. The blast is then shut off, the plug of clay removed, and the molten stream flows out sparkling and bright, the light and heat becoming more and more intense as it rolls on and increases in volume. In order to

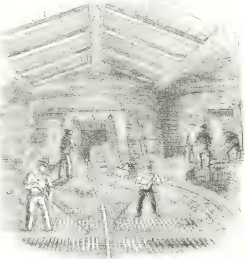

FIG. [illegible]. CASTING PIG-IRON.

make the metal flow regularly into the side channels, it is necessary here and there to interrupt the progress of the stream by a long piece of wood, as the metal does not continue sufficiently fluid to fill them up equally without this precaution. The moulds form the metal into semi-cylindrical bars called *pigs*, united by one of larger dimensions called a *sow*, the moulds being so arranged as to make the points of connexion very thin between the pigs and the sow, so that the pigs are easily broken off when the casting is cold. When the crucible is emptied, the clay plug is restored, the blast is put on, and the operations of the furnace proceed as before, day and night, weekday and holiday, for years together;[1] for it is absolutely necessary to keep up the heat of the furnace, and this can only be done by keeping it at work; for should it once cool down, this huge and costly piece of apparatus would be ruined.

The quality of pig-iron produced in an ordinary blast-furnace from clay iron-stone, and with coke as the fuel, is subject to considerable irregularity; but the experience of years has enabled the skilful iron master to classify the irregularities, so to speak, into marketable products. Six different kinds of pig-iron are distinguished. The first three, named No. 1, No. 2, and No. 3, are considered as *foundry metal*: they contain carbon in different degrees, but all of them in a higher degree than those selected for making bar or malleable iron. No. 1 is saturated with carbon, the effect of which is to produce a soft iron, very fluid when melted, so that it will adapt itself perfectly to the shape of the mould, and is hence used for small and ornamental castings. It is also so soft as to yield readily to the chisel. No. 2 contains less carbon than No. 1: it is not so soft when cold, nor so fluid when melted; but being harder and stronger, is preferred for those parts of machinery which require strength and durability. The quantity of carbon contained in these two sorts renders them unfit for being manufactured into bars; but No. 3, or *dark-grey iron*, containing less carbon than No. 1 or No. 2, can be used either for the forge or for the foundry. It is employed in heavy castings, such as tram plates, heavy shafts, wheels, cylinders of steam-engines, &c. The next quality is called *bright* iron, from its being of a lighter colour and of a brighter lustre than the foregoing varieties. It is used for large castings, but is not sufficiently fluid for fine work. A fifth variety is *mottled* iron, the fracture of which is mottled with grey and white. It is too thick and brittle for the foundry, and its use is confined to the forge. The last variety is called *white* iron, from its silvery white colour. It is quite unfit for casting on account of its thickness and extreme brittleness. It contains a smaller proportion of carbon than any other sort of pig iron; indeed its production often depends upon a deficiency of fuel in the charge.

The different kinds of iron present different phenomena in flowing out of the furnace. They have been well described by Mr. Mushet. "When fine, (No. 1.) or super-carbonated crude iron is run from the furnace, the stream of metal, as it issues from the fauld, throws off an infinite number of brilliant sparkles of carbon. The surface is covered with a fluid pellicle of carburet of iron, which, as it flows, rears itself up in the most delicate folds. At first the fluid metal appears like a dense ponderous stream, but as the collateral moulds become filled, it exhibits a general rapid motion from the surface of the pigs to the centre of many points; millions of the finest undulations move upon each mould, displaying the greatest nicety and rapidity of movement, conjoined with an uncommonly beautiful variegation of colour, which language is inadequate justly to describe. Such metal in quantity will remain fluid for twenty minutes after it is run from the furnace, and when cold will have its surface covered with the beautiful carburet of iron already mentioned, of an uncommonly rich and brilliant appearance."

Very different are the phenomena presented by the inferior iron, No. 4. From all parts of the fluid surface is thrown off a vast number of metallic sparks, arising from a cause different to that exerted in the former instance. The absence of carbon renders the metal liable to the oxidising influence of the atmospheric air. Small spherules of iron are ejected from all parts of the surface, to the height of 2 or 3 feet, when they inflame, and separate with a slight hissing explosion into a great many particles of brilliant fire, forming oxide of iron. "The surface of oxygenated iron, when running, is covered with waving flakes of an obscure smoky flame, accompanied with a hissing noise, forming a wonderful contrast with the fine rich covering of plumbago in the other state of the metal, occasionally parting, and exhibiting the iron in a state of the greatest apparent purity, agitated in numberless minute fibres from the abundance of carbon united with the metal." As the oxygenated iron cools, its upper surface becomes covered with a scale of blue oxide, which being removed, a number of deep pits are presented. "This iron in fusion stands less convex than carbonated iron, merely because it is less susceptible of a state of extreme division; and, indeed, it seems a principle in all metallic fluids, that they are convex in proportion to the quantity of carbon with which they are saturated." The appearance of No. 2 and of No. 3 in a state of fusion, present some of the phenomena both of No. 1 and of No. 4.

The quality of the metal can also be judged of before it is run from the furnace, by the colour and form of the scoriæ, the colour of the crust upon the working bars, and the quantity of carburet attached to it. That cinder which indicates the presence of carbonated iron in the hearth of the furnace, forms itself into circular compact streams, which become

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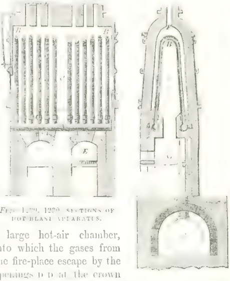
(1) A well constructed furnace will work [illegible] years without requiring repair, and then only the refractory lining will have to be renewed. Some of the Welsh furnaces have been worked for [illegible] years without requiring any extensive repairs, and [illegible] only the lower portions of the lining have required reconstruction, the upper part of the lining being exposed to only a moderate temperature, has been known to last for nearly forty years.

consolidated and inserted into each other: these are from 3 to 9 feet in length. "Their colour, when the iron approaches the first quality, is a beautiful variegation of white and blue enamel, forming a wild profusion of the elements of every known figure. The blues are lighter or darker, according to the quantity of the metal, and the action of the external air while cooling. When the quality of the pig-iron is sparingly carbonated, the blue colour is less vivid, less delicate, and the external surface rougher and more sullied with a mixture of colour." The furnace-cinder when No 3 iron is produced, assumes a long zigzag form. "Its tenacity is so great, that if while fluid a small iron hook be inserted into it at a certain degree of heat, and then drawn from it with a quick but steady motion, 20 or 30 yards of fine glass thread may be formed with ease. When by accident a quantity of this lava runs back upon the discharging-pipe, it is upon the return of the blast impelled with such velocity as to be blown into minute delicate fibres, smaller than the most ductile wire. At first they float upon the air like wool, and when at rest very much resemble that substance." The cinder frequently crystallizes in cooling: cells or cavities form among it, which on being opened, are sometimes found full of perfectly crystallized forms.

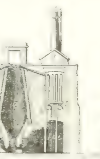
THE HOT-BLAST.—The enormous quantity of air injected into a blast furnace to promote the combustion of the fuel, must have its own temperature raised before its oxygen can combine with the carbon of the fuel in the way of combustion. In fact one portion of the heat of the furnace is expended in raising the air to the temperature necessary for the combustion of the remaining fuel: a second portion of the heat is carried off by the nitrogen of the injected air, and by the volatilized products; while a third portion is employed by the ore and the flux; so that not only is there a wasteful expenditure of heat, but the very means employed to raise the temperature of the furnace, has the effect of keeping down the temperature. If, however, the temperature of the air be raised to about 600° before it is injected into the furnace, a much higher temperature can be obtained with the same charge of fuel, or the same temperature with a diminished charge of fuel. It has been calculated that by the use of the blast at 572° instead of 60°, a furnace may have its temperature raised one-eighth; and supposing the temperature obtained by working with cold air to average 2,700°, the hot-blast will raise it to 3,060°, making a difference of 360° in the effective heat of the furnace. Hence many substances infusible in a cold-blast furnace, become fusible in a hot. Coal can be used in the hot-blast furnace instead of, or mixed with coke; less fuel and less limestone flux are required; and ores previously unfitted for the manufacture of foundry iron can be smelted.

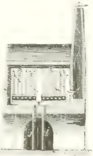
Figs. 1229, 1230, are vertical and lateral sections of the apparatus for heating the air which supplies the blast. It consists of a kind of stove, in which the air is made to pass through a series of cast-iron pipes before arriving at the nozzles by which it is injected into the furnace. A A is the wall of the furnace, B B, a section of one of the syphon-shaped tubes, arranged as in Fig. 1230, from 6 to 8 inches in diameter. These are connected by sockets and iron joints to horizontal pipes A of much greater diameter. E is the fire-place for heating the pipes, which are surmounted by a large hot-air chamber, into which the gases from the fire-place escape by the openings D D at the crown of the arched covering F. The draught is regulated by a damper placed over the top by which the openings can be more or less closed by moving a compound lever. The large cylinder J, Fig. 1230, communicates with the cylinder by which the blast is supplied, and is large enough to neutralize the vibrations occasioned by the oscillation of the piston by which air is forced into the furnace. The horizontal connecting-pipe A, through which the cold air enters the stove, is furnished with a stop or diaphragm in the middle, and the air, in order to escape by the pipe on the opposite side, must traverse the syphon-pipes B, the heat of which raises the temperature of the blast to the proper point. In most cases each tuyere is provided with a heating apparatus; and in a furnace producing 60 tons of cast-iron per week, from 30 to 35 tons of coal will be required in that time for raising the blast to the temperature of 600°.



FIGS. 1229, 1230. SECTIONS OF HOT BLAST APPARATUS.

It has been proposed to employ the highly-heated gases which escape from the throat of the furnace, for the purpose of heating the blast with which it is supplied. When it is considered that one of the large Scotch furnaces yields from 150 to 200 tons of iron per week, with a consumption of from 300 to 400 tons of coal, and that from 4,000 to 5,000 cubic feet of air per minute is injected into it, we may form some idea of the enormous waste of heat in the volumes of smoke and flame which are being constantly discharged from its chimney. Many methods of applying this waste heat to the heating of the blast have been proposed, but most of them have been objectionable on account of the difficulty of repairing the apparatus without blowing out the furnace. The least objectionable method is that by Mr. Budd, as employed at the Ystalyfera Iron-works in South Wales. The heating ovens are arranged so as to be quite distinct from the furnace, so that they can be repaired without interfering therewith. The stoves are built in the masonry a little below the throat of the furnace, and a chimney, 25 feet higher than the top of the platform, affords the means of drawing into them as much of the hot air and flame as may be required. This arrangement will be understood from Fig. 1231, in which *a* is the furnace, *b* a series of flues situated about 3 feet from the top for conveying the hot air into the chamber *c*, Fig. 1232, in which are placed the arched pipes *d*, heated by the gases from the furnace. The heat of the stove is regulated by the chimney *e* and its damper *f*. The cross-pipes *g* connect together the upright air-tubes *d*, and the side pipes *h* convey the blast which arrives by the upcast mains *i*, to the various cross-pipes. The heated air is afterwards conveyed to the tuyeres by the downcast pipes *j l*. There is also a door *k* in the the brick-work to allow the apparatus to cool before going in to make repairs. The gases which escape from the furnace have a temperature of about 1,800°, so that it is only necessary to draw through the chamber such a supply (about one-sixth of the whole quantity has been found sufficient) as will heat the stream of air in the tubes to 600°. To do this the gases should leave the stove at 800°. If the temperature of the hot-air chamber decline, it may be raised by slightly elevating the damper *f*. At the Ystalyfera works, another portion of the waste gases is conducted through flues, and made to heat the boilers which supply the engine of the blowing machine, and there is still a large amount of heated air and flame which passes off without doing any service. The economy of fuel by these arrangements is about one-third, so that 2 tons of coal produce the same quantity of iron as was formerly produced by 3 tons.





From the results of some experiments by Messrs. Bunsen and Playfair, upon a hot-blast furnace near Alfreton, in Derbyshire, it was concluded that 81·54 per cent of the heat generated by the furnace is continually carried off by the unconsumed gases escaping from the chimney. This estimate appears to be excessive, but there is no doubt that the amount of heat thus wasted is very large. In Great Britain, where the abundance of fuel leads to its extravagant expenditure, little more has been done to apply this vast body of heat to useful purposes, than to heat the blast or the boilers of the steam-engine, as already stated. On the Continent, however, some successful attempts have been made to apply this heat not only to the above purposes, but also to the roasting of the ores, and to the refining and puddling of iron. For this purpose the gases are drawn off from the furnace, cooled and purified by being passed through water, and when ignited, they burn with a very intense heat. In some cases air-pumps are employed to propel the gases to the places where they are to be used as fuel.

The chemical changes which take place in a hot-blast furnace were examined by Messrs. Bunsen and Playfair, in 1845, in the furnace already indicated. This furnace is 40 feet high, 11 feet wide at the boshes, and is blown with air heated to 626°, under a pressure of 6.75 inches of mercury, the diameter of the nozzles being 2¾ inches. The furnace is supplied in the course of 24 hours with 80 charges, each consisting of 420 lbs. of calcined ore (clay carbonate of iron), 390 lbs. of coal, and 170 lbs. of limestone. The coal and ore are charged in large lumps: the limestone in lumps about the size of the fist. The product of each charge is stated to be 140 lbs. of pig-iron.

In order to collect the evolved gases, a wrought-iron tube was passed into the furnace to the various depths at which it was desired to examine the products of combustion; and to the upper extremity of this tube was attached a leaden pipe, by which the gases were conducted into proper vessels for analysis. At a certain depth the heat of the furnace was so great that the iron tube became fused. A small hole was therefore bored through the masonry from the front of the furnace to its internal cavity, so as to reach the hearth just beneath the boshes, at a distance of six feet from the bottom of the crucible, and two feet nine inches above the tuyeres. The gas drawn off from this opening exhaled a powerful odour of cyanogen; and in kindling it, the flame exhibited the purple tint characteristic of that substance. Analysis showed an amount of cyanogen equal to 1·34 per cent. The other results, as obtained at various depths from the top of the furnace, are exhibited in the following table, which will also show the various changes produced by the current of air during its passage from the tuyeres to the chimney:—

	Depth from the top.							
	I. 8 ft.	II. 11 ft.	III. 14 ft	IV. 17 ft.	V. 20 ft.	VI. 23 ft	VII. 24 ft	VIII. 34 ft
Nitrogen . . .	54·77	[illegible]	50·95	[illegible]	[illegible]	58·28	[illegible]	58·05
Carbonic acid .	[illegible]	9·41	[illegible]	[illegible]	10·83	8·19	10·08	0·00
Carbonic oxide	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29·97	[illegible]	[illegible]
Light Carburetted Hydrogen . .	[illegible]	4·57	[illegible]	[illegible]	4·40	1·64	[illegible]	0·00
Hydrogen . . .	[illegible]	[illegible]	12·42	[illegible]	4·83	[illegible]	[illegible]	3·18
Olefiant Gas . .	0·85	[illegible]	1·57	[illegible]	0·00	[illegible]	0·00	0·00
Cyanogen . . .	0·00	0·00	0·00	0·00	0·00	trace	trace	1·34

It will be seen, from the production of carburetted hydrogen, that the coking of the coal goes on even to the depth of twenty-four feet. At a depth of fourteen feet, the amount of nitrogen is least; while at the same depth the amount of hydrogen and carburetted hydrogen is greatest: this, therefore, appears to be the zone of the most active distillation It was found by analysis that 100 parts of the furnace-coal yielded a mean of ·769 sal ammoniac; and as 280 cwt. of coal were consumed in twenty four hours, it follows that 2 cwt. of sal ammoniac might be obtained from it, as a secondary product, simply by conducting the gas, previous to its application as fuel, through a chamber containing muriatic acid. The quantities of carbonic oxide and carbonic acid have no proportional relation to each other; but it would appear, from the constant results obtained at the depth of twenty four feet, that below this point there is a continuous liberation of carbonic acid, obtained either from the limestone flux, or caused by the reduction of the oxide of iron, or probably from both sources. Judging, however, from the average composition of the gases evolved from the materials employed, the excess of carbonic acid may be due to the flux, the reduction of the ore taking place at the boshes only. But "the most important feature of this investigation is the discovery of the presence of large quantities of cyanide of potassium in the lower region of the furnace. On introducing an iron pipe into the hole pierced in the front of the masonry above the tuyeres, large quantities of this substance were readily collected. To do this, the iron tubing, in order to prevent its being fused, was inserted to within a certain distance only of the internal cavity of the furnace; and to its outer end was attached a series of receivers, in which the various products were cooled and collected. From the quantities thus obtained from a given volume of gas, it was calculated that at least 224 lbs. of cyanide of potassium were daily generated in the furnace. When the iron tube used in this experiment was withdrawn from the hole, it was found to be internally encrusted with melted cyanide of potassium, which became deliquescent on exposure to the air." The sources of the potash were the calcined ore, which contained 0·743 of potash, and the coal, which contained 0·07 per cent. It had been shown by Mr. Fownes, "that cyanide of potassium is produced on passing a current of nitrogen gas over a mixture of charcoal and carbonate of potash, strongly heated in an iron tube; "and it consequently appears that the cyanogen present is furnished solely by the direct union of the liberated nitrogen with a portion of the carbon constituting the fuel. Since, also, potash is reduced at a high temperature in the presence of carbon, it follows that no formation of cyanide of potassium in the region immediately above the tuyeres is due to the direct union of carbon with potassium, and the nitrogen of the air. The presence of this substance in the hearth of the furnace cannot fail to effect extensive chemical changes, and influence, to a considerable extent, the reducing power of the apparatus. It has been shown that, at very elevated temperatures, this salt is volatile; and if, therefore, it reaches the part of the furnace in which the reduction of the ore is effected, its high reducing properties will necessarily come into play. By this means it must become decomposed into nitrogen, carbonic acid, and carbonate of potash, of which the two former will pass off in the form of gas, while the latter, not being volatile, is carried down by the other materials in the furnace, until it reaches the point at which it is again transformed into cyanide of potassium. In this way we can easily understand that the accumulation of cyanide of potassium may ultimately become very considerable, and capable of materially influencing the action of the apparatus. When the proportion of this salt has become increased beyond a certain amount, the excess is probably decomposed, by the action of the blast, into nitrogen and carbonic acid, which escape in the gaseous form, and into carbonate of potash, the potash of which unites with the siliceous matters present, and is carried off by the slag. It is evidently very difficult to determine the exact nature of the various chemical actions continually taking place in the different parts of an apparatus of such immense size and so highly heated as a blast furnace; but it is certain that the presence of large quantities of a material of a character so highly reducing as cyanide of potassium cannot fail to materially influence the chemical changes which are there effected. The amount of this substance is probably greater in hot blast furnaces than in those at which air at the ordinary temperature is employed; but the quantity generated even in the cold-blast furnace must to a certain degree modify the reactions before described, and contribute to the reduction of the ores."[1]

SECTION VI.—THE MANUFACTURE OF WROUGHT IRON.

The cast, or pig-iron, produced by the operations which have been thus far described, is contaminated with impurities, which render it brittle, and incapable of being wrought into shape by the hammer. The impurities consist chiefly of carbon and silicium, together with small portions of sulphur and phosphorus. The carbon and silicium are got rid of by exposing the pig-iron for a considerable time to oxidizing influences, such as heat and a blast of air. The effect of this is to convert the iron into oxide of iron, which forms first on the surface, and gradually penetrates into the mass. The carbon of the iron reduces the oxide first formed, producing metallic iron and carbonic oxide gas. By a similar reaction, the silicium of the iron is converted into silicic acid, which, combining with a portion of the oxide of iron, forms a fusible silicate of iron. These actions and reactions are continued, until at length the whole

(1) Phillips's Manual of Metallurgy. The Report of the experiments by Messrs. Bunsen and Playfair was made to the British Association for the Advancement of Science in the year 1845, and is published in the 15th volume of the Reports. It is entitled "Report on the Gases evolved from Iron Furnaces, with reference to the Theory of the Smelting of Iron."

mass is converted into a spongy mass of malleable iron and fusible slag. This is subjected to the percussion of a heavy hammer, or to great pressure, whereby the silicates are pressed out. The whole of the silica of the slag is not due to the silicium of the iron: a considerable portion of it comes from the sand which adheres to the pigs in the casting; another portion may also be derived from the coke used in the refining-furnace.

The cast-iron pigs also contain small portions of sulphur and phosphorus, which must be carefully removed during the refining, as their presence would effectually destroy the valuable properties of wrought iron. The separation of these substances is, however, a matter of great difficulty, so that it is better to get rid of them previous to smelting, by a careful roasting of the ore; but if the source of sulphur be the iron pyrites of the fuel, a large dose of carbonate of lime must be added to form sulphuret of calcium, which then escapes with the slags. The phosphorus may be removed by similar means; but ores containing much phosphorus or sulphur can never be made to furnish good iron.

A furnace which supplies iron for the refinery is worked so as to produce that variety of cast-iron called *white-iron*, on account of its containing a very small proportion of carbon. For this purpose the charge of ore is large in proportion to that of the fuel; and the blast is urged at high pressure in order to determine the rapid descent of the ore. The ore ought to be of good quality.

The English method of refining pig-iron consists of two consecutive operations carried on in separate furnaces. In the first, which is called the *fining-furnace*, or the *refinery*, the metal is melted, and, after being exposed to the blast of numerous tuyeres, accumulates in the bottom of the crucible, whence it is run off into a flat mould. By this operation it loses a considerable portion of the carbon, and nearly all the silicium, becomes very hard and brittle, and its surface covered with small blisters similar to some of the varieties of steel. In this state it is called *fine metal*. It is broken up and transferred to what is called a *puddling-furnace*, in which the operation of decarbonization is completed.

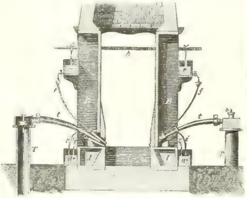


Fig. 1233. THE REFINERY

The refinery is usually built on a mass of brickwork, about nine feet square, and the hearth is raised only a small height above the level of the floor. The hearth H, Figs. 1233, 1234, is 2½ feet wide, and 3½ feet long. It is formed by the junction of four cast-iron troughs, I, through which a stream of cold water is made to circulate, to prevent them from being fused by the heat. The bottom of the crucible is of gritstone or argillaceous sand, and is slightly inclined in the direction of the tapping-hole *o*. The air, which is supplied by blowing cylinders, similar to Fig. 1223, enters the hearth through the six tuyeres *t*, which are inclined at an angle of from 25° to 30°, and so arranged that the blast from each may be directed towards the face of the opposite side of the furnace, not in opposition to the opposite tuyere. The tuyeres are furnished with double casings, through which cold water is constantly running. A supply of water is brought by a pipe *p* into the reservoirs *e*, whence it passes to the tuyeres, through the pipes *f*, and escapes through the tubes *c′* into the tanks *w*, into which the water from the iron troughs flows by the syphon tubes *c*. A furnace of this kind consumes about 400 cubic feet of air per minute. This is supplied by the pipes T, which are furnished with screw-valves at *s* for regulating the supply. Above the hearth is a chimney 16 to 18 feet high, supported by four cast-iron columns, so as to allow free access to the fire on all sides. The tapping-hole *o* is placed in one of the shorter sides of the hearth, and by it the melted metal and the slag flow out into the mould C, where the metal is cooled by quenching with water. The plate of fine metal thus formed is about 10 feet long, 2½ feet broad, and 2 inches thick. A thin crust of slag forms upon its surface; but the greater portion is collected in a small pit at the lower end of the mould. As soon as one charge of metal is run out, the hearth is prepared for another. The workman first detaches, by means of a long rod, any portions of metal that may be adhering to the sides of the furnace; he then presses down the fuel, throws in a fresh supply of coke, and levels it to the proper height: upon this he arranges six iron pigs, four parallel to the long sides of the furnace, and two across. The weight, which may vary from 20 to 30 cwt., takes about two hours in refining, and the

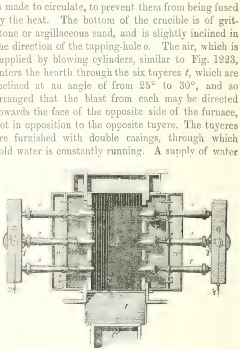


Fig. 1234. PLAN OF REFINERY.

loss is from 13 to 17 per cent. In about a quarter of an hour the iron melts down, and falls in drops through the blast to the bottom of the furnace. A portion of the metal thus becomes oxidized, and, uniting with the silica of the fuel, and also with that formed by the oxidizing of the silicium of the metal, forms a fusible vitreous slag, which, being rich in oxide of iron, exerts a powerful decarbonising action on the iron on which it floats. To promote these changes, the blast is made to play upon the fused mass for a considerable time after the whole of the iron has been collected at the bottom of the crucible. During this time the fuel is lifted up by the motion caused in the metal by the escape of carbonic oxide produced by the reaction of the rich silicate of iron of the slag. When the decarbonization is thought to be sufficiently advanced, the hole *o* is opened, and the metal allowed to flow into the mould. A considerable quantity of cold water is thrown upon it, whereby it becomes extremely brittle and sonorous. The slags are then broken in pieces for the puddling-furnace. About 10 tons of cast-iron may be passed through the refinery in the course of twenty-four hours, with the consumption of from 4 to 5 cwt. of coke for each ton of metal refined. For the better kinds of iron, such as that used for the manufacture of tin-plates and iron wire, where the tenacity of the pure metal is required, coke is too impure a fuel; charcoal is therefore used; but as with this fuel the metal collects into clots or lumps, they are formed into a bloom which is conveyed to the helve, and flattened into thin plates, preparatory to being finished in another furnace.

In the puddling-furnace, shown in sectional elevation and plan, Figs. 1235, 1236, the hearth A is of fire-brick set on edge, or it is a plate of cast-iron, covered with a layer of slag, which is made to incline towards B, where there is a considerable fall to allow of the escape of the slags formed during the process of puddling; and they are removed by the *flosshole*, *h*. The hearth is about 6 feet long and 4 feet wide at the widest part, and taper to about 20 inches towards the chimney. It is heated by a fire at F, from which it is separated by a bridge *b* 10 inches high. The fire-bars are made movable for the purpose of removing the clinkers; and the draught is determined, through the furnace, by a chimney from 30 to 50 feet high, furnished at the top with a damper, D, which can be raised or lowered by means of a chain and lever. The opening at E, which communicates with the grate, is usually closed by heaping up the coal used for the fuel. The opening D communicates with the hearth, or sole of the furnace, and is chiefly used for working the metal with an iron bar during the process of puddling. It is closed by an iron frame filled with fire-bricks, and is raised by a chain and lever. Another opening nearer the chimney is used for charging and for cleaning out the furnace at the end of an operation. The whole furnace is very strongly built: it is encased with cast-iron, and held together by clamps and wedges. The chimney is also strengthened by iron ties.

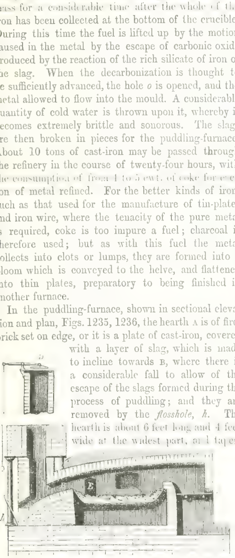


Fig. 1235. PUDDLING FURNACE.

The charge of fine metal is piled up on the sides of the hearth, until it nearly touches the dome, the centre of the sole being left clear for working the charge, and allowing the hot air to circulate about it. A portion of rich slag and iron scales is added; the doors and the damper at the top are closed, and fresh fuel is added to the fire. In about half an hour the metal begins to melt and flow on the bottom of the hearth. The man removes a small iron plate from a hole in the working door, passes in an iron rod, and stirs up the molten metal so as to expose fresh surfaces to the oxidizing influence of the draft, and moves it further from the bridge, to prevent the whole of the charge from running together. When the charge is brought into a uniform pasty mass, the fire is lowered by gradually closing the damper, and, if necessary, throwing a little water into the furnace. The metal now, from the escape of carbonic oxide gas, assumes the appearance of boiling, and the gas burns at the surface with its characteristic blue flame. The metal is kept constantly stirred with an iron *paddle*, so as to expose fresh surfaces to the action of the gases; the direct action of the atmosphere is avoided as much as possible by keeping the working-door closed, otherwise the metal would be too much oxidized. By continuing to work the metal

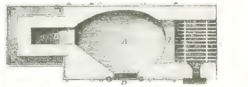


Fig. 1236. PLAN OF PUDDLING FURNACE.

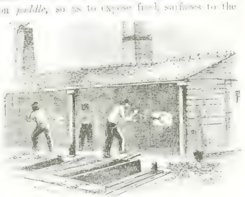


Fig. 1237. PUDDLING.

it loses its consistency, and becomes *sandy*, or, as the workman calls it, *dry:* the evolution of carbonic oxide ceases, but the puddler continues to work the metal until it appears uniformly granular. The fire is then gradually urged, and the increased temperature causes the sandy particles to agglutinate; the iron is then said to *work heavily.* A portion of the slag is run off through the flosshole, and the man then proceeds to *ball up*, or to form the iron into balls. For this purpose he attaches a small portion to the end of his paddle, and, rolling it round, other fragments weld on to it. When a ball of 60 or 70 lbs. weight has been formed, it is detached from the paddle, and another is formed in a similar manner. When the whole of the charge has been balled, it is moved into the hottest part of the furnace, by means of a kind of rake called a *dolly*, and the fire is urged so as to weld the metallic particles. Each ball is then lifted out of the furnace by means of heavy tongs, and conveyed to the shingling hammer, or to the squeezer, where an iron rod is welded to it by way of a handle; the slag is pressed out, and the metal consolidated. The whole operation of puddling occupies about 2½ hours. At the end of the first 20 or 25 minutes, the metal begins to fuse, and in another hour is completely reduced to a sandy state, in which it is kept for another half hour, when the balling is commenced and occupies about the same time. From 10 to 11 charges, of 3½ to 5 cwt. each, are passed through the furnace in the course of 24 hours. The fine metal loses about 9 per cent. in the puddling, and occasions the consumption of about its own weight of coals.

The hammer used in compressing the balls is shown in Fig. 1238. It is made of cast iron, and is about 10 feet long, the weight of the helve being about 3½ or 4 tons. The axis *a* rests on heavy plummer blocks well secured by strong bolts passing through courses of wooden beams into a foundation of masonry. The wood serves to diminish the concussion of the ponderous mass. The head H is of wrought iron faced with steel, and weighs from 7 to 8 cwt: it is passed through a hole in the helve and well secured with wedges. The pane of the hammer *p* as well as that of the anvil is formed into a series of grooves for the purpose of better nipping and compressing the ball. The face of the anvil is supported on a block of iron *i* of about 4 tons weight. The head is raised by a number of cams *c*, fixed in a heavy collar B, called the *cam-ring bag*, about 3 feet in diameter, fixed to a powerful shaft S, which is turned by steam or water power assisted and regulated by a heavy fly-wheel, a portion of which is shown in the figure. In this way the head is lifted from 16 to 24 inches, and makes from 75 to 100 blows per minute. When it is desired to suspend the operation of the hammer, the rod *p'* is pulled, this brings into a vertical position the prop *p*, which supports the hammer and keeps it free of the cams.

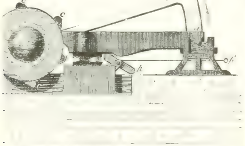


Fig. 1238. THE HELVE, OR SHINGLING HAMMER.

The squeezer, which sometimes takes the place of the hammer, is shown in Fig. 1239. It consists of two powerful jaws *a b*, united at *c*, as in a pair of shears: the meeting faces of the jaws are furrowed with numerous grooves in order to hold fast the bloom. The lower jaw *b* is hollow to allow a current of water to flow through it to keep it cool. The upper jaw is set in motion by the shaft, and the crank *k* worked by the fly of which *c'* is the centre. This press is said to squeeze out the slag more thoroughly and expeditiously than the helve does, but on this subject there is a difference of opinion among iron masters. Nasmyth's steam-hammer has also been applied to the same purpose.

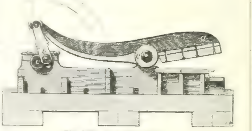


Fig. 1239. THE SQUEEZER.

As soon as the slag is pressed out of the bloom, and while it is still at a red heat, it is passed between cylinders or *rolls*, Fig. 1240, which serve to compress and weld together the metallic particles, to express the last portions of the slag, and to draw out the iron into bars. Two sets of rolls are usually employed, the one called *roughing* rolls, which prepare the iron for the *finishing* rolls, the latter being differently grooved according to the section intended to be given to the bar. The rolls R R′ R″ R‴, are mounted one above the other in pairs in a massive iron frame-work *u u*, connected by heavy couplings *d e*, tightly screwed together. Motion is communicated by strong toothed wheels made to turn either way, and the distance between the rolls is regulated by screws *s s*, attached to the bearings in which the trunnions work. The bearers *b* are connected at the upper part by stout iron bars, which are used to support the heavy tongs used in lifting the blooms. Below the roller frame is a channel through which a stream of water flows, and in it is collected the scale which falls from the surface of the heated iron while passing through the rolls; and a stream of water is made to play from a small pipe *t* upon each pair of rolls to keep them cool. The whole arrangement rests upon a massive foundation of timber, masonry and cast iron. The roughing rolls are about 5 feet in the clear between the bearers, and 18 inches in diameter. "Each of these rollers has a series of from 5 to 7 regularly decreasing grooves of an elliptical form, so arranged that the shorter axis of the figure formed by the meeting of the corresponding grooves in the two cylinders is equal to the longer axis of the ellipse formed by the junction of the two grooves which come next in succession. The smaller axis of each ellipse is also invariably prependicular to the surface of the two cylinders, by the meetings of which it is formed; and for this reason, every bar which has passed between the rollers, is made to describe a quarter revolution before it enters the grooves which come next in the series, and is thus equally compressed and drawn out in all its parts." The roughing and preparing grooves are usually arranged on distinct rollers, as in the figure, where R R′ represent the roughing rolls, and R″ R‴ those for forming the metal into bars, which are afterwards cut up by the shears, formed into faggots, welded together and drawn into bars of the required section. The first 3 or 4 grooves of the roughing rolls are roughened with teeth to cause the iron to pass through without slipping; and on a level with the bottom of the notches on the lower roll is a thick plate of cast iron, called an *apron*, for supporting the balls or masses of iron which are to be passed through the rollers.

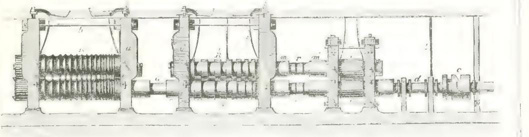


Fig. 1210. ROLLS.

The iron produced in this way is hard and brittle, and subject to flaws and imperfections. It is well adapted to railway bars, which are prepared by passing the bloom of puddled iron through grooved rollers of the section of the bar required. Good bar iron is, however, prepared by a separate process already indicated and now to be described. The bars from the roughing rolls are first cut up into short lengths by the shears, represented in Fig. 1211, consisting of two jaws, to which are firmly bolted cutting edges *a b* of hardened steel. The lower blade is fixed, but the upper one moves on a stout pin P, and is attached by a lever P R to a rod R M, which is connected by a crank to the shaft of the steam engine, so that at every revolution of the axle by which the power is supplied, the jaws of the shears are made to open and shut alternately. Bars of an inch or more in thickness are easily divided by the jaws.

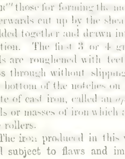


Fig. 1211. SHEARS.

A number of the short lengths thus produced are *piled* or faggoted together in a reverberatory furnace, which differs chiefly from the puddling furnace in having a larger grate in proportion to the hearth, a more intense heat being required. It is important to preserve the faggots from the oxidizing influence of the air, so that no air is allowed to get to them, except that which has passed through the grate. When the faggots have attained the proper welding heat, they are taken out one at a time and thrown to the men at the finishing rolls, who pass them through the grooves as rapidly as possible, so as to get the required section and dimensions before the bar has cooled below the proper temperature for drawing. The finishing rolls are formed much more accurately, and revolve at a much higher speed than the roughing rolls. The latter make about 70 revolutions per minute: rolls of medium size about 140, and small rolls 230 or 240. The grooves gradually diminish in size, and the bar is passed from one to the other until the required size is attained. For small bar iron, 3 rollers placed one above the other are sometimes employed. Motion being directly communicated to the centre roll, this by means of cogged wheels causes the other two to revolve in contrary directions. The heated bar is passed between the first and second rolls, and then returned from the other side between the second and third. Sheet iron is made by passing the metal between smooth faced rollers, which are gradually screwed nearer together as the desired thickness is being approached. Two sets are used; in the first the metal is roughed, and in the second finished off, and the surface made even and polished. The metal requires a reheating between the processes. The sheets intended for the manufacture of tin-plate are polished by being subjected to hydraulic pressure between two smooth surfaces of cast iron.[1]

The short lengths which compose the pile, tend to produce a fibre in the bar, which in good iron is always perceptible however perfect the weld. In rolling flat bars, the layers of the pile are kept horizontal, in order that the fibres may be as straight and parallel as possible. The experienced blacksmith in working up his bars always attends to the direction of the fibre, because by doing so he can make the most of his iron and increase the strength and toughness of the articles produced.

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[1] At the Russian Exhibition of the Works of Industry, (1852,) one of the sheet iron excited great attention; 7,040 square feet were rolled from a hundredweight of iron. This would give a thickness of about [illegible]th of an inch. It was proposed to use this [illegible] for paper. A book [illegible] and the iron [illegible] as flexibly as paper. It is proposed to print for the [illegible] on these metallic [illegible], and thus render books secure from [illegible] the white [illegible]

Bar iron is known in the market by the names *common iron, best iron, best best* or *chain-cable iron.* The different kinds of iron used in the manufacture of gun-barrels are described under GUN.

Two common defects of bar iron are known as *red short* and *cold short.* Red short iron is that which cracks when bent or punched at a red heat, although it may be sufficiently tenacious when cold. Cold short iron on the contrary is weak and brittle when cold, but can be worked without difficulty when hot. The quality of a bar of iron may be tested by nicking it at one side with a chisel and then breaking it or doubling it down at the notch. If the iron be cold short, it will break off at once with the blow of a sledge-hammer. But if the bar be of good quality, it will not break off but bend double, and those portions of it to the depth of the notch on both sides will separate a little from the body of the bar, and split up like a piece of fresh ash stick, exhibiting a clear, distinct, silky fibre. If this appearance be produced on a cold bar, and it be then raised to a cherry red heat and bent first in the direction of the pile, and then at right angles to it without cracking on the outer side of the bend, it is of excellent quality, neither red-short nor cold-short. A very small amount of phosphorus will make bar iron brittle, so small a proportion as 0.5 per cent. having been found to make it cold-short. Sulphur has been assigned as the cause of the red-short property of wrought iron; the presence of only 0·0001 of sulphur renders the iron very difficult to work at a welding heat. A cold-short iron is generally produced from a lean ore, in which case it has been found desirable to mix with it the rich red hepatic ore of Lancashire and Cumberland, which if smelted alone would produce red-short iron. In this way two opposite defects are made to correct each other, and iron of average strength is produced.

SECTION VII.—THE MANUFACTURE OF STEEL.

Iron in its pure form is known only to the scientific chemist; in its manufactured state it is never entirely free from carbon and other substances. The carbon appears to be only mechanically mixed with the metal, a peculiar process being required to effect a chemical union between the two, the result being a *carburet of iron* or *steel.* Less than ½ per cent. of carbon chemically combined with iron develops those remarkable properties which distinguish steel from iron, and adapt it to purposes for which iron is inadequate. Thus steel is so much harder than iron that it will cut and file it; steel will scratch the hardest glass; strike sparks with siliceous stones; it is denser than iron, has a finer grain, assumes a brighter and whiter lustre when polished, acquires greater elasticity retains magnetism more permanently, and does not rust so easily. When heated it assumes various beautiful tints of colour, and if suddenly cooled it becomes harder, more brittle, and less pliable than iron. Indeed the chief value of steel depends upon the ease with which it can be hardened and tempered to any degree between extreme hardness and softness.

Ordinary wrought iron may contain about 0·25 per cent. of carbon without having that property of steel whereby it becomes hard by being suddenly cooled in water: but with 0·50 to 0·60 per cent. of its weight of carbon, it emits sparks on being smartly struck with a flint. But the quantity of carbon required to render iron steely, depends greatly on the purity of the metal: shear steel after tilting contains from 1 to 1·5 per cent. of carbon: with more than 1·75 per cent. the steel cannot be welded. Iron with 2 per cent. of carbon cannot be forged; but with 1·9 per cent. of carbon iron may with care be worked under the hammer; and this appears to be the extreme point of carbonization beyond which steel is converted into cast iron.

A pure iron is required for the manufacture of steel, such as the charcoal iron of Sweden and Russia. A similar iron made at Ulverstone, and one from Madras, are also used. The foreign iron is imported in bars, on which certain marks are stamped by the manufacturers, and which distinguish it in the market. The most celebrated iron mine of Sweden is that of Dannemora, about 30 miles to the north of Upsala. The ore contains limestone, quartz, and actinolite, and affords from 25 to 75 per cent. of cast iron, which is as white as silver, crystalline, and very brittle. It is converted into malleable iron by heating in a bed of charcoal, and hammering out into bars, in which state it is whiter than common iron, less liable to rust, and distinctly fibrous in texture. This iron is known at Hull (the English port to which it is shipped) by the name of *Oregrund* iron, from the name of the port at which it is shipped. The marks which distinguish this iron are the *hoop L,* (so called from the letter L inclosed in a hoop); the G L, and the *double bullet.* Inferior Swedish iron is known by the marks *C and crown, D and crown:* the *Steinbuck,* and the *W and crowns.* All these marks are shown in Fig. 1242.

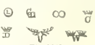

Fig. 1242.

It is remarkable that steel is produced on the continent of Europe by a process directly the reverse of that followed in England. We manufacture steel by the addition of carbon to pure malleable iron by what is called the process of *cementation.* In Germany, Styria and Silesia steel is made by depriving some of the better kinds of cast iron of the excess of carbon contained in them, one portion being got rid of by oxidation, while another portion is made to combine chemically with the fused mass.

The *cementing furnace* in which iron is converted into steel in this country is shown in section Fig. 1243. Externally it resembles a glass-house, and consists of a cone or hood 30 or 40 feet high, serving to shelter the furnace within and also to carry off the smoke of the fuel. Within the furnace are two chests or troughs, c c, in which the bars of iron to be converted are buried in pounded charcoal. These troughs are made of fire-tiles or firestone grit, and are capable of holding from 8 to 12 tons of bar iron. They are from 8 to 15 feet long, and from 26 to 36 inches in width and depth; but those of small capacity are said to produce the most uniform quality of steel. Below and between the troughs, and extending their whole length, is a grate, F, open at each end where it is supplied with fuel, and the fire is kept up as equally as possible during the process, the flame being directed equally round the troughs by a number of air holes and flues, *o o*, leading to the chimneys. The draught is further aided by an opening in the middle of the arch of the furnace. The troughs are, of course, filled before the fire is lighted, (the workman entering the furnace by the opening under M,) and the preparation of hard charcoal dust, called *cement*, varies with different steel converters: charcoal made from hard wood is preferred; but soot is sometimes used; as also a proportion of ashes (about $\frac{1}{10}$th) and a little common salt.[1] The workman sifts this mixture to the depth of two inches over the bottom of the troughs; puts in the bars upon their narrow edges, with a space between every two bars of from half to three quarters of an inch; powder to the depth of an inch is then sifted over this layer; a new series of bars is next made to fit into the interstices between the first, care being taken that no two bars are in contact, and in this way the troughs are filled to within 6 inches of the top. The filling is then continued with old cement powder, and this is lastly covered with refractory damp sand or fire-tiles, for the purpose of excluding the air, which, if admitted, would greatly injure or altogether stop the process of cementation. The entrances to the furnace being carefully closed, the fire is lighted below the troughs and carefully urged for two, three, or four days, until the proper cementing heat is attained: this heat is maintained during several days more until the iron has absorbed the quantity of carbon requisite to form the kind of steel required by the manufacturer. From six to eight days are sufficient for the production of moderately hard steel—such, for example, as that known by the name of *shear* steel; softer steel, for saws and springs, requires a shorter time; harder steel, for making the chisels used in cutting iron, takes a longer period; and for some purposes bars are exposed to two or three successive processes of cementation, and are hence said to be *twice* or *thrice converted*.

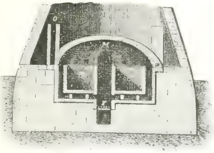

Fig. 1245. SECTION OF CEMENTING FURNACE

In the centre of the end-stones of the cementing troughs are small holes, called *tasting holes*, corresponding with small iron doors in the outer brickwork; by these holes the workmen can occasionally draw out a bar to see how the transmutation is going on. This is judged of by the *blisters* which appear on the surface of the bars, which give the well-known name of *blistered steel* to this article. When by this process of *tasting* the change is judged to be complete, the fire is extinguished and the furnace left to cool for about a week, when the process for making blistered steel is finished.

This steel is very different from the bar iron from which it was produced. Its surface is covered with blisters, and on breaking a bar across, its texture is seen to be no longer fibrous, but granular or crystalline; the colour is white like frosted silver, and the crystals are large in proportion to the amount of carbon absorbed.

The cementation of steel may be effected by exposing the iron at a proper temperature to the action of carburetted hydrogen gas. Steel of excellent quality may be produced in this way, but the process does not appear to be sufficiently economical to admit of its being generally introduced. It has also been proposed to convert the retorts used in the manufacture of coal gas into cementing troughs: the bars of iron to be put in with the charge of coal, and taken out with the coke, or after a second charge of coal has been coked.

TILTING. The bar of blistered steel contains numerous fissures and cavities, which render it unfit for forging except into a few rough articles. To prepare it for forging into edge-tools and cutting instruments, it requires to be condensed and rendered uniform, which is the object of the next process, called *shearing*, the *shear steel* thus produced being originally employed in the manufacture of shears for cutting off the wool from sheep.[1] The process is also called *tilting*, from the circumstance of a tilt hammer being employed.

In some respects the operation of tilting resembles that of *shingling* described in the manufacture of iron; but the tilt hammer is differently arranged. In shingling, where only a slow motion is required, the hammer is lifted up by means of levers attached to a cam revolving under the nose of the helve. In the tilt hammer the cogs of a wheel are made to act on the tail of the helve, pressing it down, and thus

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(1) The use of ashes and salt in the cement has not been explained. Mr Phillips suggests that the salt may tend to volatilize any siliceous particles contained in the charcoal, and prevent their entering into combination with the iron during the process of carbonization.

(1) Shear steel [illegible] *Newcastle steel*, from the circumstance of steel of this quality having first been made at Newcastle; but a better quality introduced from Germany gave rise to the term, *German steel*.

causing an elevation of the head of the hammer, and a rapidity of motion, which could not evidently be produced by the arrangement of the shingling hammer; for, in this, the levers must be sufficiently wide apart, to allow the hammer head a clear space to fall through. In the tilt hammer, however, where the motion is applied at the tail, the number of levers may be considerably multiplied; because, from the position of the axle, the tail describes a very small arc between every two levers; and this small motion will cause the head to pass through a much larger space in the same time, thereby producing rapidity of motion, and considerable force. The construction of the tilt hammer will be better understood from Fig. 1244. The frame work is strongly secured to the masonry and timber of the foundations, so as to form a firm bed for the block. The shaft of the hammer is made of timber secured by wrought iron rings and fitted into a cast iron socket with trunnions or axles cast upon it, which turn in brasses in a block. The wheel C by which the hammer is elevated is furnished with ears or *tappits*, which, during the revolution of the wheel, engage the end *t* of the shaft and continue to depress it until disengaged, when the hammer head *h* falls with considerable force on the anvil, producing in this way from 150 to 360 strokes per minute.

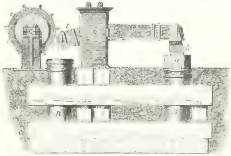

Fig. 1244. TILT HAMMER.

The blistered steel is prepared for tilting by breaking the bars into lengths of about 18 inches, and binding four or more of these into a faggot by means of a slender steel rod. One of these fragments is left longer than the rest to serve as a handle, or a pole of iron is used for that purpose, as is shown in Fig. 1245. The faggot is then raised to a welding heat in a wind furnace, and is covered with sand, which combining with a small portion of oxide of iron, forms a fusible slag over the metal, and prevents it from wasting or burning away. When first removed from the furnace it is placed under a forge hammer, which unites all the fragments and closes up internal fissures. The rod thus produced is again heated, the binding rings are knocked off, and the tilt hammer comes into operation. The workman is seated on a board, suspended by iron rods from the ceiling of the mill-house; whereby he is enabled with a very slight motion of his foot to advance or recede with ease and rapidity, so as to cause every part of the bar to receive the blows of the hammer in quick succession. As the anvil is nearly on a level with the floor, the workman is seated in a kind of pit excavated for the purpose; he is attended by two boys to bring hot rods and to remove them after they are hammered. "In small rods, the bright ignition originally given at the forge soon declines to darkness; but the rapid impulsions of the tilt revive the redness again in all the points near the hammer; so that the rod skilfully handled by the workman progressively ignites where it advances to the strokes. Personal inspection alone can communicate an adequate idea of the precision and celerity with which a rude steel rod is stretched and fashioned into an even, smooth, and sharp-edged prism, under the operation of the tilt hammer. The heat may be clearly referred to the prodigious friction among the particles of so cohesive a metal, when they are made to glide so rapidly over each other in every direction during the elongation and squaring of the rod."

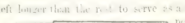

Fig. 1245.

A visit to the tilt house is by no means pleasant to a stranger; several hammer heads, each weighing from 150 to 200 pounds, falling from three to four hundred times per minute upon solid metal anvils, *a*, Fig. 1244, produce a stunning noise and a vibration which can be felt through the whole body. This vibration is checked as much as possible by carrying the foundation of the tilting apparatus to a depth of ten or twelve feet, forming a heavy mass of masonry; and the anvil is made to rest on a massive wooden pillar B, strongly secured by wrought iron rings, which is supported by, and forms part of the masonry.

By tilting, the steel is formed into bars of about an inch and a half broad, and three-eighths of an inch thick; all the loose parts and seams of the blistered steel are closed, and it is now capable of being polished, which could not be done before: it is also more malleable, and can be forged with the hammer into shears, edge-tools, and cutting instruments. The value of the steel increases with the amount of tilting which it receives: it is therefore not uncommon to cut a tilted bar into several pieces, form them into a faggot, and elongate this again into a bar or rod. The terms *double shear*, *single shear*, and *half shear*, express the amount of doubling and welding which the bars have received.

CAST STEEL. Steel is produced in the greatest perfection by the process of *casting;* that is, the bars of blistered steel being broken into fragments, are melted in crucibles and then poured, while in a fluid state, into ingot moulds. The heat required to produce this fusion is very great, so that the crucibles or melting pots require to be made with refractory fire-clay and with the greatest care, in order to exclude bubbles of air and extraneous substances, which might expand or ignite in the furnace, and thus endanger the stability of the melting pot.

The crucibles are made of Stourbridge clay mixed with one half of an inferior clay from Stannington, near Sheffield: a small quantity of coke dust and of fragments of old pots is added, and the whole is kneaded into a perfectly uniform and smooth mass. The clay is first mixed with water, worked up, and then spread out in a thin layer on a shallow trough on the floor.[1] There it is kneaded during five or six hours by the naked feet of two men, who with a shuffling kind of motion go over every part of the surface, pressing it down quite flat; and so sensitive is the touch of their feet, (which are developed to an enormous size by this constant exertion,) that they can, by the difference in the tread, detect an air bubble, a fragment of straw or of dirt in the clay. The two latter they pick out with the fingers, and get rid of the air by making a slight incision with a knife. When the whole surface has been well trodden over, it is folded double and trodden out again so as to occupy the whole of the trough. If the reader has ever watched the domestic operation of making pastry, he will be able to form a good idea of the process of kneading clay for the steel-melting pots.

Fig. 1246. TREADING OUT THE CLAY, AND MOULDING THE CRUCIBLES.

The crucibles are about two feet in height, and of the shape shown in section, Fig. 1249. They are formed in a cylindrical mould of cast iron *a a′*, Fig. 1247, which is open at the two extremities. This cylinder is inserted into a sole of cast iron *b b′*, firmly attached to a block of wood and having a raised circular edge. In the centre of the sole, corresponding with the axis of the cylinder, is a hole intended to receive the supporting rod of the inner mould *c*. This consists of a block of hard wood, the surface of which corresponds with the interior shape of the crucible: through the centre of this block passes a strong iron axis, the lower end of which rests in the hole already mentioned; the upper end, which is rounded, rises just above the circular cover of wood *e e′*. It will be seen that when the inner mould *c* is in its place, as in Fig. 1247, there is between its surface and the inner surface of the outer mould a vacant space of the form and dimensions required for the melting pot. The surface of *c* and the inner surface of *a* having been smeared with oil, a quantity of clay is put into *a*, and the central plug *c* forced down as far as it will go by hand: its further descent is then urged by blows of a hammer upon the rounded head of the iron axis, until the lower end of the axis passes into the hole in the sole *b*. In order to disengage the moulded clay, the central plug *c* is pulled out and the hole in the centre stopped up: the outer mould with its contained clay is then lifted upon a block of wood mounted upon a stout iron rod, Fig. 1248, and of somewhat less diameter than the bottom of the pot, so as to press entirely upon the clay bottom when the mould *a a′*, lifted out of *b b′*, is placed upon the top of Fig. 1248. The mould is then allowed to descend slowly and with care, by which means the clay pot is left upon the top of the block of wood, while the mould *a a*, on reaching the ground, surrounds the rod, Fig. 1248. The upper part of the clay is then finished by hand: it is pressed slightly inwards and made to assume the form, Fig. 1249. The blocks on which the pots rest are short cylinders of clay: the covers, also of the same material, are thick discs slightly raised in the centre. Each crucible, which weighs about 25 lbs., is removed as soon as it is finished into a heated vault, where it gradually becomes dry; and some hours before being used the crucibles are brought to a red heat for the purpose of annealing them. A crucible can seldom be used for melting the steel more than three times without cracking; so that there is a constant demand for crucibles, as many as 108 being required per week for a ten-hole furnace.

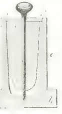

Fig. 1247.

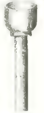
Fig. 1248.

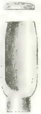
Fig. 1249.

On a level with the crucible-making department are the furnaces for melting the steel; these are ordinary wind furnaces placed in connexion with a tall chimney by which a strong natural draught can be obtained. (See Fig. 1250.) Each furnace is only just large enough to contain two crucibles and the proper amount of fuel; and it is lined with a plaster calculated to resist the intense heat. This plaster is formed of the dust of the roads in the vicinity of Sheffield, and is called *ganister*. The fuel employed is a dense well-made coke, broken into lumps of about the size

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[1] Stourbridge clay contains—

Silica	[illegible]
Alumina	[illegible]
Combined water, and combustible and volatile matters	[illegible]
Carbon	[illegible]
	[illegible]

Hence, the only fixed principles of Stourbridge clay are silica and alumina. The Stannington clay contains small portions of manganese and lime, and a trace of oxide of iron. The melting pots fuse into a vitreous enamel of extreme hardness. They can only be used for three meltings, but if made of Stourbridge clay alone, they will stand six.

of a hen's egg. Immediately over each furnace is a trap-door, made of fire-bricks fastened in an iron frame opening into the casting house, which is a kind of shed entirely open on one side, while on the other ten trap-doors are seen, from the sides of which escape a few rays of red light indicative of the fiery furnaces below. In an adjoining shed the bars of blistered steel are broken into fragments, and the charge for each crucible, about 30 lbs., weighed out into tin trays, a small portion of black oxide of manganese being added to each charge, this substance being supposed to improve the quality of the steel. In some cases powdered charcoal forms part of the charge. Fig. 1250 shows the interior of the casting house and of the air-vault, with two crucibles, as they are arranged in the furnace; a portion of the tall chimney is also seen in section: on the shelves of the casting house the green crucibles are left to season.

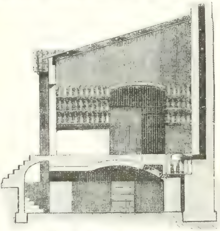

Fig. 1250. CASTING HOUSE AND AIR VAULT.

The empty crucibles are put into the furnace upon a sole of baked fire-clay, and the charge is given to each by means of a long funnel of iron plate. Each pot is carefully covered over with a lid of a more fusible clay than the body of the crucible, and sometimes a small quantity of bottle glass or blast furnace slag is put in above the steel fragments, so as to form a sort of vitreous coating to prevent the air from oxidizing the metal. When the pots are thus charged and covered in, the furnace is filled up with coke and kept well supplied. In about four hours the steel is in a state for casting, and as the time approaches the men occasionally lift up the various trap-doors and examine the crucibles, their eyes being accustomed through the fierce floods of heat which pour upwards from the furnace to detect the precise time when the metal is sufficiently fluid for casting.

While the steel is melting, the ingot moulds are prepared. These moulds, which are of cast iron, are of various sizes, according to circumstances; those which were used at the time of the writer's visit producing an ingot about two inches square, and two feet in length, a quantity equal to the contents of one crucible. When an ingot of unusually large size is required, such as for rolling into a piston-rod or a large plate for a circular saw, the mould is, of course, of proportional size, and receives the contents of two or more crucibles. Each mould consists of two parts, forming a long hollow cavity, the parts fitting accurately together: they are held together by a clamp of iron, Fig. 1251: and are kept upright by resting against the angles of a pit in the floor of the casting house. Previous to putting the moulds together, the interior is smoked by being laid across a pitch fire, the internal coating of carbon thus imparted preventing the liquid steel from adhering to or melting the mould.

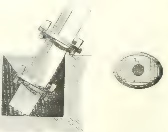

Fig. 1251.

Just before drawing the crucibles, each man puts on sacking leggings, and an apron of the same material; he next visits a tank, and thoroughly soaks these in water, as a further protection against the fierce heat to which he is about to be exposed; then, throwing open the trap-door of one of the furnaces, he removes a portion of the white hot coke, and, planting his feet one on each side of the yawning fiery furnace, thrusts down a pair of tongs, Fig. 1252, furnished with concave jaws for grasping the crucible just below the swell, and then, with a motion between a jerk and a swing, raises the glowing burden. A second man immediately removes the cover; a third man, and the most skilful, grasps the crucible with tongs held horizontally, raises it, and slowly inclines it to the mouth of the ingot mould, his attendant with a pair of tongs removing any portions of cinder or slag from the surface of the molten metal. Considerable skill is required in *teaming*, as the operation of transferring the metal from the crucible to the ingot mould is called. It must be poured directly down the centre of the mould, without touching the sides; for were it to do so, it would instantly remove the carbonaceous covering, and burn a piece out of the mould. The metal flows as liquid as water, and with the gurgling sound of water if poured under similar circumstances; but the extremely high temperature of the molten steel is shown by the white heat slightly tinged with blue. As the stream falls, minute portions of it combine rapidly with the oxygen of the air, and take fire, producing brilliant scintillations. The fire even communicates itself to the ingot towards the end of the process of teaming, and the mould then appears like a brilliant firework; but this combustion is soon stopped by the insertion of a solid plug. As the ingot immediately solidifies, each mould is opened directly after the teaming, and the

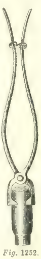

Fig. 1252.

ingot is turned out in a red-hot state. This rapid cooling of the steel and the thin film of soot effectually protect the mould from the destructive action of the liquid metal which would otherwise ensue.

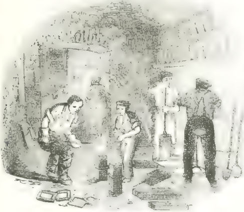

Fig. 1253. CASTING STEEL INGOTS.

The men engaged in these operations have that peculiar look about the eyes which shows the nature of their occupation; but otherwise, we believe, the business of steel refining is not considered unhealthy, and the men receive good wages.

As soon as the crucible is emptied of its contents, it is returned to the furnace, to receive a fresh charge; and as four hours are required for the melting, there are three casts in the twelve hours during which the men work. The charge is introduced by means of a funnel of plate iron, Fig. 1254, into which a rod is inserted, to break up the charge, and prevent a heavy mass from falling at once into the crucible, which might cause its fracture.

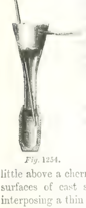

Fig. 1254.

Cast steel is much denser and harder than tilted steel, but it requires care in forging, because a little above a cherry red heat it is very brittle. Two surfaces of cast steel may be welded together by interposing a thin film of borax; and cast steel may be firmly united to a polished surface of iron by placing the iron in the mould into which the steel is poured. The two metals can then be rolled and worked out together into rods adapted for forging.[1] Fig. 1255 shows the operation of rolling steel. It does not differ greatly from rolling iron, and therefore need not be further described.

Fig. 1255. ROLLING STEEL.

When steel is moistened with a drop of dilute nitric acid, a dark grey spot is produced: malleable iron so treated yields a spot of a green colour.

When steel is fused with very small quantities of platinum, of silver, rhodium or iridium, its hardness is greatly increased; but these alloys have not yet been used in manufactures.

Sheffield and its neighbourhood is the great seat of the steel manufacture. The annual quantity of steel produced a few years ago, varied from 16,000 to 17,000 tons from foreign iron, and from 1,500 to 2,000 tons from iron of British manufacture. The number of converting furnaces was upwards of 120, each of which was capable of converting weekly 6 tons of iron: the coal consumed in the process was about equal to the weight of steel produced. There were also above 100 melting furnaces for cast steel, each containing about 10 holes for crucibles: 4 tons of coke were used in making 1 ton of cast steel, and each furnace of 10 holes produced $4\frac{1}{2}$ tons of cast steel per week. [See APPENDIX.]

IRRIGATION. This art, as practised in warm countries, has been noticed in our article DRAINAGE, to which with its illustrations we refer the reader, but the mode of irrigating an English water-meadow is essentially different. In the East it is the ordinary custom to introduce water on the soil, and leave it in a stagnant condition for months, the water thus affording a valuable and necessary protection both to the soil and the tender plants, from the effects of the great heat. But in our own country, where no such necessity exists, great care is taken that the water shall not accumulate on the soil so as to become stagnant, while at the same time it shall be supplied in ample quantity all the time the plants are growing. Hence in our best systems of irrigation, the draining is as essential as the flooding, and while one set of channels is made to distribute the water slowly and regularly over the meadow, another set is devoted to the opposite purpose of carrying it off. Thus a constant flow of the water is maintained, accelerated or retarded by small hatches, so as to keep it at the desired level. The feeders, or channels which supply the

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(1) Various particulars respecting the forging, hardening, and tempering of steel, are given under CUTLERY. See also ANNEALING—CASE HARDENING, &c. The damasking of steel is noticed under GUN. In this notice of the manufacture of steel, we have availed ourselves of information contained in the Editor's work on the "Useful Arts and Manufactures of Great Britain." The pictorial illustrations are from drawings made for the purpose by Mr. Prior, at Sheffield. The reader interested in the manufacture of steel, will do well to study the elaborate memoirs on this subject, by M. F. Le Play, in the Fourth Series of the *Annales des Mines*. The memoir contained in vol. iii. 1843 is devoted to the fabrication of steel in Yorkshire, while that in vol. ix. 1846, is on the fabrication of steel in the north of Europe.

water, are formed on the top of low ridges, the drains in the hollows between them, and this further aids in keeping up the flow of the water.

In preparing to irrigate lands, the first step is to take the level, and to ascertain what are the supplies of water to be obtained above that level, and whether such supplies are available without deteriorating the property of others, or withdrawing water from some important use elsewhere. If no natural supply of water can be obtained above the level, and if water cannot be conducted to a reservoir for the purpose, then the irrigation of the land is impossible. On the other hand, it does not follow as a matter of course that every low land where a supply of water can be readily obtained is capable of irrigation, for there must also be the means of carrying off the water, as well as of bringing it on.

The most general and natural position for water-meadows is on the banks of running streams. At some point in the course of the river a canal is dug along the bank, and carried perhaps to a considerable distance from the river. Into this a portion of the water is diverted which will keep the same level as that part of the river where it has its origin: in some cases a dam D, (Fig. 1256), is constructed across the river R, so as to secure a large quantity of water at the most advantageous time for irrigation. A certain command of water being thus obtained, it is directed into a main channel or conductor *a*, in connexion with various smaller channels or feeders. From these the water overflows into the drains with which they are intersected, and which carry it into the main drain *b*, whence it is conveyed back again to the river, unless there be other lands at a lower level to which it can be transferred, when the main drain in its turn becomes a conductor to a second system of feeders, and so on. But this method, which is called *catchwork*, is only available when there is a considerable fall of water, and a gentle declivity towards the river. It is also only desirable when the supply of water is limited, for its fertilizing qualities rapidly deteriorate.

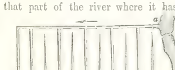

Fig. 1256.

The best season for irrigation is not always that in which the heat and drought are the greatest. In fact, at such season, much mischief would be done by injudicious flooding, while in the depth of winter, when it might be supposed that watering is needless, valuable results are often obtained from the practice. "During frost," says an experienced writer, "when all dry meadows are in a state of torpor, and the vegetation is suspended, the water-meadows, having a current of water continually flowing over them, are protected from the effect of frost, and the grass will continue to grow as long as the water flows over it. Too much moisture, however, would be injurious, and the meadows are therefore laid dry by shutting the flood-gates, whenever the temperature of the air is above freezing. By this management the grass grows rapidly at the first sign of spring. Before the dry upland meadows have recovered the effects of frost and begun to vegetate, the herbage of the water-meadows is already luxuriant. As soon as they are fed off, or cut for the first crop of hay, the water is immediately put on again, but for a shorter time; for the warmer the air, the less time will the grass bear to be covered with water. A renewed growth soon appears, and the grass is ready to be cut a second time when the dry meadows only give their first crop. Thus by judicious management, three or four crops of grass are obtained in each season, or only one abundant crop is made into hay, and the sheep and cattle feed off the others." The soil best adapted for a water-meadow is a gravel or other porous soil free from stagnant water, hence under-draining is sometimes necessary, before the laying out of a good meadow. When the beds are properly laid out and rolled, grass seed is sown, or the turf parings laid down again, or tufts of grass from old sward are spread over and soon cover the ground.

The herbage produced in England is some of the best in the world: it is more varied, close, and fine than that of southern countries, and more rich and vigorous than that of northerly climates. It is watered by numerous rivers, which flow through districts of great fertility, and afford valuable nutriment, owing to the quantity of animal and vegetable substances with which they are enriched. Liquid manure is also applied to the land in the same way, being distributed and carried off like water. Muddy water is sometimes let into a field, and allowed to remain until it has deposited its sediment, when it is let through sluices. This is called *warping*, and is practised where circumstances will allow of it, at the mouths of rivers, where the tides and the fresh water meet. At the estuary of the Humber the water is carried several miles inland, and will deposit in the course of a single season more than a foot of rich soil. When lands become gradually inundated through natural causes, if the flooding does not continue too long, it may have a beneficial effect by the deposits left behind; but when the inundation begins to subside, it must be made to run off entirely, and not be left to settle in pools, which would destroy the grass.

ISINGLASS. See Gelatine.

ISOCHRONISM—ISOCHRONOUS, (from ἴσος, *equal*, and χρόνος, *time*.) Vibrations or oscillations performed in equal time are said to be isochronous. It is a remarkable property of all systems which are in stable equilibrium, that when disturbed therefrom by a greater or less impulse, the oscillations by which they recover their original position are all performed in the same time, or so nearly so, that any acceleration or retardation is quite imperceptible. This valuable property of isochronism is taken advantage of in the construction of instruments for measuring time. See Horology.

ISOMERISM, (from *ἴσος*, *equal*, and *μέρος*, *part*,) a term applied to that natural law by which certain bodies may contain the same elements in the same ratio, and yet possess distinct physical and chemical properties. Isomeric bodies are of constant occurrence in organic chemistry. For example, formic ether and acetate of methyle are isomeric, both containing $C_6 H_6O_4$; but as a difference in chemical properties is fairly and properly attributed to a difference in *constitution*, if not always in composition, it has been attempted to show that isomeric bodies vary in this way. Thus formic ether may consist of formic acid C_2HO_3 combined with ether C_4H_5O; and acetate of methyle may consist of acetic acid $C_4H_3O_3$, and the ether of wood spirit C_2H_3O.

ISOMORPHISM, (from *ἴσος*, *equal*, and *μορφή*, *shape* or *form*.) Certain substances of similar chemical constitution possess the remarkable property of exactly replacing each other in crystallized compounds without alteration of the characteristic geometrical figure. Such bodies are said to be *isomorphous*. For example, magnesia, oxide of zinc, oxide of copper, protoxide of iron, and oxide of nickel are isomorphically allied. The salts formed by these substances with the same acid and similar proportions of water of crystallization, are identical in form, and when of the same colour cannot be distinguished by the eye: the sulphates of magnesia and zinc may be thus confounded. The sulphates, too, all combine with sulphate of potash and sulphate of ammonia, giving rise to double salts, whose figure is the same, but quite different from that of the simple sulphates. In the same manner alumina and peroxide of iron replace each other without change of crystalline figure. The alumina in common alum may be replaced by peroxide of iron, the potash by ammonia or by soda, and the figure of the crystal remain unchanged.

Mixtures of isomorphous salts cannot be separated by crystallization, unless of very different degrees of solubility. A mixed solution of protosulphate of iron and sulphate of copper, isomorphous salts, yield on evaporation crystals containing iron and copper. But if, before evaporation, the protoxide of iron be peroxidized, the crystals will be free from iron. The peroxide salt of iron is not isomorphous with the copper salt, and easily separates from it.

When compounds thus correspond, it is inferred that the elements which compose them are also isomorphous. It is difficult, and often of course impossible, to ascertain the crystalline figure of most of the elementary bodies, and the difficulty is increased by the fact that many of them are *dimorphous*, that is, they exhibit two forms.[1]

IVORY. A beautiful and compact substance, obtained from the tusks of the elephant, the narwhal, the walrus, and the hippopotamus, and also from the teeth of the same animals. The best and largest supply is however from the elephant.

The male elephant when full grown has two tusks, varying considerably in size in different animals, but most valued when they are large, straight, and light in colour. These tusks are hollow at their insertion into the jaw, and for a considerable space therefrom, but become solid as they taper towards the extremity. The principal sources whence they are obtained are the western coast of Africa and Hindostan; but the African tusks are most esteemed, as being denser in texture, and less liable to turn yellow. By an analysis, the African show a proportion of animal to earthy matter, of 101 parts to 100; while in the Indian it is 76 to 100.

The applications of ivory are so numerous that a large demand for elephants' tusks has existed for a lengthened period. During twelve years at the close of the last century, the imports into Great Britain amounted on an average to 1,576 cwts. annually; in 1831 and 1832 they had increased to 4,130 cwts., of which 2,950 cwts. were retained for home consumption. Now, reckoning the medium weight of a tusk at about sixty pounds, it is evident that the imports of the year last named would require 7,709 tusks, or the destruction of 3,854 male elephants. But since that period the imports have so greatly risen, that in Sheffield alone 180 tons of ivory are worked up annually into knife-handles, &c. It is also affirmed that of the quantity of tusks imported, although some weigh from 60 to 100 pounds, yet the number of small tusks is so great that an average weight of nine pounds can only now be reckoned on; in which case 45,000 tusks, from 22,000 elephants are required to supply the demand of this great cutlery mart of England. Occasionally, it is allowed, broken or shed tusks are collected, or those of animals which die a natural death are obtained; but the supply from these sources is never very large, so that the slaughter of elephants, after all deductions made, is going on at a rate which leaves it a constant wonder that the breed of this noble animal has not been sensibly diminished. The value of the ivory consumed in Sheffield is very great; but there are also other seats of manufacture, and ivory is wrought into the forms of chess-men, billiard-balls, the keys of musical instruments, thin plates for miniatures, mathematical and other instruments, and an immense variety of small objects of use, amusement, or ornament. None of our manufacturers have yet reached the consummate skill of the Chinese in the workmanship of ivory, chiefly remarkable in their concentric balls, their chess pieces and models. Yet the adaptation to useful purposes of this valuable substance is fully understood by those who cannot rival the exquisite minuteness of Chinese art. A manufacturer of surgical instruments in Paris is in the habit of rendering ivory flexible for use as tubes, probes, &c., by acting on the well-known fact, that when bones are subjected to the action of hydrochloric acid, the phosphate of lime, which forms one of the component parts, is extracted, and the bones retain their original form, and acquire great flexibility. M. Charrière, after giving the pieces of ivory their required form and polish, steeps them in acid, either pure or diluted, until they become supple and elastic, and of a slightly yellow colour. In the course of drying the ivory returns to its original hardness, but its flexibility can be easily restored by surrounding it with wet linen, or by placing wet sponge in the cavities of the pieces. In some cases, the articles have been kept in the acidulated water, in a flexible state, for a week, without change or injury, and without acquiring any taste or disagreeable smell.

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[1] Fownes' Manual of Elementary Chemistry. [illegible].

It was stated some years ago that the decay of articles in ivory could be effectually checked, even when its progress had advanced so far as to cause the specimens to crumble away under the hands. Some of the works in ivory forwarded by Mr. Layard from Nineveh, were found on their arrival in England to be in a state of rapid decomposition. Professor Owen was consulted on the subject, and he suggested a remedy which is said to have proved successful, thereby preserving to this country these curious relics of ancient art. Concluding that the decay was owing to the loss of gelatine in the ivory, he recommended that the articles should be boiled in a solution of gelatine. Under this process they became apparently as firm and solid as when they were originally entombed.

The tusks of the hippopotamus afford a very hard and white ivory. These are usually short and much curved, hollow at the place of insertion, and covered with a glossy enamel. They vary in weight from three or four pounds to thirty. These are highly prized by the dentists, and are better adapted than any other ivory for making artificial teeth. The thick coat of enamel which covers them has first to be removed, for this entirely resists steel tools, and under it is found a pure white ivory, with a slight bluish cast. The parts rejected by the dentists are used for small carved and turned works. The horn or tooth of the narwhal is also hard and susceptible of a fine polish. The largest size is ten feet long; at the lower extremity it forms a slender cone of a twisted or spiral figure.

Another and a very remarkable source of ivory is that which supplies almost the whole of the ivory-turner's work made in Russia. Along the banks of the larger rivers of the Russian Empire, and more particularly those of further Siberia, thousands of tusks are annually dug up, which once constituted the weapons of defence of a species of elephant or mammoth now extinct. These form what is called *fossil ivory*, but they have not undergone the changes usually understood in connexion with the term fossil, for their substance is as well adapted for use as the ivory procured from living species. So numerous are these tusks, that they are occasionally exported from Russia, being cheaper than recent ivory. They are rarely to be met with in England, except in museums. Mention is made, however, of one which measured 10 feet in length, and was solid to within 6 inches of the root, weighing no less than 186 lbs.: this was cut up into keys for piano-fortes.

There is a substitute for ivory now in general use, which it is necessary to notice here. It is the fruit of a species of palm, imported from Peru for some time past into the European market, and named by two Spanish botanists, who met with it in the groves of Peru, *Phytelephas macrocarpa.* These writers also supply the following description:—"The Indians employ the leaves of this most beautiful palm as a covering to their cottages. The fruit at first contains a clear insipid fluid, with which travellers quench their thirst; this fluid afterwards becomes gradually sweet and milky, and at length acquires solidity, so as to be as hard as ivory. If the fruit be gathered while the juice is fluid, the latter soon becomes acid; but when allowed to attain perfection, the kernels are of sufficient hardness to be employed by the Indians as knobs for walking-sticks, reels of spindles, and little toys, which are white, and perfectly hard while dry; if they are put under water they soften, but on drying, their hardness is restored. Bears eagerly devour the young fruit." Two species of this palm are recognised, the *P. macrocarpa*, or large-fruited, and *P. microcarpa*, or small-fruited. The vegetable ivory is in fact the albumen or nutritious substance surrounding the embryo, and which in some other palms, as the cocoa-nut palm, constitutes a beautiful and firm substance lining the shell. The vegetable ivory is enclosed in a hard rind, some of which generally adheres to it as imported. The Doum Palm has a similar albumen, which is turned into beads for rosaries.

The African ivory, as already stated, is superior to any other: its appearance, when first cut, is mellow, warm, and transparent, almost as if soaked in oil, and with very little appearance of grain or fibre; the oil dries considerably by exposure, and a permanent tint then remains, a few shades darker than writing paper. The Asiatic ivory is more dead-white at first, but is more disposed of the two to turn yellow afterwards. It is also less dense, and does not take so high a polish. The choice of ivory is accompanied with much uncertainty, even to experienced buyers. The tusks are received in all varieties of size and figure. They may be 8 or 10 feet long, or only as many inches. They may weigh (as we learn from the magnificent specimens in the Great Exhibition), 325 lbs. the pair, or they may not reach as many ounces. Mr. Holtzapffel mentions a small and hollow tusk in his possession, which only weighs 2½ ounces. Their curvature may describe a simple half circle, or they may be curved in two directions, the tusk inclining to the shape of the letter S. The outside may be dark-coloured almost to blackness, or it may run through all the varieties of light and deep orange, hazel, and brown; their ends may taper off to a fine point, or they may be very much worn away, or they may end abruptly as if broken off.

The buyer, therefore, has to make the best selection he can by choosing a tusk as nearly straight, solid, and round as possible, with a smooth rind free from cracks, and a point that gives evidence in the worn part, that the tusk is of the desired fineness of grain. Yet after all precautions, it is only after the first cut of the saw that the quality can be really determined. Sometimes the interior exhibits a succession of layers or rings, of different shades and degrees of transparency; sometimes the solid parts of the most beautiful and transparent tusks have long and patches of opaque white ivory, in some cases a regular grain is observable, almost like the engine-turning of a watch-case; in others no grain is perceptible; occasionally there is a deficiency of animal oil, and the ivory crumbles under the workman's tool; or there may be the serious defects of darkness of colour, and coarseness of grain. In rare instances a considerable portion of the tusk is found to have been injured by a musket ball, the iron or leaden bullet being enclosed in it. Two instances, if not more, have occurred in which these bullets were of gold, showing that the shot was fired by royal hands, for it is the reputed custom among Eastern potentates to use gold or silver bullets in their sports. One of these golden bullets is stated to have been cut through by a comb-maker in dividing a tusk. The portion of the tusk thus injured, is generally useless for any ornamental purpose for many inches each way around the ball; but cases have occurred in which a ball, and even a spear-head, has entered at the thin part near the skull of the animal, and become embedded without injury to the external surface.

Great economy is used in cutting up the tusks, so that the only waste may be that which arises from the passage of a thin saw between the several pieces into which it is divided; and even here it can hardly be termed waste, for the clean saw-dust of the ivory is sometimes used in making jelly. Every portion is, in fact, turned to some account, the outside rind being used for handles of pen-knives, &c., and the scraps burned in retorts for the manufacture of ivory black, used in copper-plate printers' ink, and for other purposes. The saw used in cutting up the ivory is about the fortieth of an inch thick, with rather coarse teeth, about five or six to the inch: it is stretched in a steel frame to keep it very tense. The sawing is commenced at the root end, and two or three pieces are cut to the lengths of such articles as can be made in that thinner portion of the tusk. The blocks are rarely cut more than five or six inches long. As the solid part of the tusk is reached, the blocks have to be greatly subdivided; perhaps longitudinal slices have to be cut for miniatures, or the taper handles of knives and razors have to be economically severed by cutting the slabs wedge form, the thick end of one against the thin end of the next, and then subdividing by parallel or inclined cuts, made either with the saw just described, or with the circular saw. The entire division of each block or length of tusk is settled and accurately marked in pencil upon the end of the piece, before the saw is used. When the tusk is to be used for turnery work only, the first cut is usually made where the hollow ends, which is ascertained by thrusting a wire up the tusk. Unless the latter is extremely curved, the principal part is formed into cylinders or rings, but the greater the curve the shorter the pieces that can be prepared from it without waste. The mode of centering the pieces, or placing them in the lathe, is thus described by Mr. Holtzapffel:—"The first process in preparing to rough-turn the block, is to fix it slenderly in the lathe between the prong-chuck and the point of the popit-head, and its position is progressively altered by trifling blows upon either end, until when it revolves slowly, and the common rest or support for the tool is applied against the most prominent parts, *a*, *e*, and *c* respectively, the vacancies or spaces opposite to each at *d*, *b*, and *f* shall be tolerably equal, so that, in fact, about a similar quantity may have to be turned away from the parts *a*, *e*, and *c*, for the production of the cylinder represented by the dotted lines within the figure.

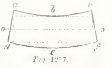

Fig. 1257.

The centres having been thus found, they should be made a little deeper with a small drill, and then the one end of the block being fixed upon the prong-chuck, the opposite extremity, supported by the centre, is turned for a short distance slightly conical, ready for fixing in a plain boxwood-chuck, or a brass chuck lined with wood to complete the rough preparation, unless, indeed, it is entirely performed upon the prong-chuck. With the decrease in length less attention is requisite in the centering, on account of the interference of the curvature of the tooth, and the pieces may at once be rasped to the circular form, and then chucked, either in a hollow chuck, or else by cement or glue, against a plain flat surface." It is recommended, however, that the amateur become familiar with the various methods of chucking on less costly materials before he largely employs ivory. Pieces of ivory in which there is a small hollow in the centre, are temporarily rendered solid by rasping a piece of beech wood, and driving it in; the work can then be centred as just explained with the hollow pieces; the process of turning is repeated on the inside, a side cutting tool, with a long handle for a secure grasp, being used, and the tool held very firmly, for which purpose the sliding rest is very desirable. When thin rings or short tubes of ivory are required, they are frequently cut one out of the other in the lathe with the parting tool, as in Fig. 1258.

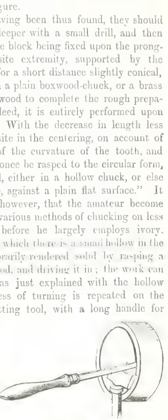

Fig. 1258.

Works intended strictly to match each other require to be cut from the same tusk, where this is possible, it being almost impossible to match works from different tusks in colour, transparency, and fibre. Works in ivory, too suddenly exposed to heat and dryness, are apt to split: on this account they should never be placed on hot chimney-pieces, or under the direct rays of the sun. Ivory resembles wood in the changes it is liable to from warping and splitting. There are some woods, indeed, less liable to vary than ivory, such as box-wood and lance-wood. In the recent Parliament Survey, drawing scales made of these woods were sanctioned by the Tithe Commissioners, as being next in accuracy to metal, while ivory scales were quite rejected, owing to their variation in length under hygrometrical influence. The change in the length of ivory articles does not, however, equal that of their width; thus billiard balls are apt to become different in their two diameters: the best are made out of tusks scarcely larger than themselves. There are various recipes for bleaching ivory when it has become discoloured, but they appear to be of very little value.

IVORY-BLACK. See CARBON, vol. i. p. 315.

JACQUARD APPARATUS. See WEAVING.

JADE. This name has been given to serpentine, nephrite, and saussurite, but is usually applied to nephrite, a massive, tough, translucent mineral, composed chiefly of silica and magnesia, with or without alumina, oxide of iron, and lime, but varying in constitution. In New Zealand and China it is valued for its supposed medical properties, and is carved into images, and polished down into amulets and various fanciful shapes. Some of the mineral from China called Yu, or Jade, is however, supposed to be prehnite. Jade is polished by lapidaries like carnelian, but only takes a greasy, and not a brilliant polish.

JALAP. A common and useful medicine, obtained from the roots of a species of Convolvulus (*C. Jalapa*) chiefly obtained from Vera Cruz, and named after the town of Xalapa or Jalapa in the interior. The roots are collected in March or April, before their resinous juices are weakened by the development of the young shoots: some of them are of great size, weighing as much as 50lbs. They are divided into portions, and hung in nets over a fire to dry. In commerce, jalap is often adulterated with roots of white briony, which are white or grey, spongy and not resinous, whereas genuine jalap is hard, resinous, with a brown shining fracture. 100 parts of the dry root have been found to yield ten parts resin, forty-four parts gummy extract, twenty parts woody fibre, and twenty nine parts starch, albumen, salts of lime, potash, &c.

JAPANNING. A method of varnishing articles in wood, metal, and other substances, originally practised by the natives of Japan, with a peculiar lacker obtained by making incisions in the lower part of the trunk of a tree, the growth of their islands, and collecting the juice. This juice is at first like cream, but becomes black by exposure to the air: it hardens better than any other lacker, and is sometimes brought over to this country, but is not generally used. The Japanese method of employing this lacker is said to be as follows:—After exposing it to the air for many hours, until it becomes of a deep black, and adding a fine powder consisting of charred wood, they then spread the lacker thinly and evenly over the article, and dry it in the sun. Another coat is then laid on, and dried as before. It is soon extremely hard, and will bear polishing with a smooth stone and water, until it becomes as even as a plate of glass: it is then wiped dry, and the forms of figures and other ornaments are traced with a pencil dipped in varnish made of boiled oil and turpentine. Before this varnish-tracing is quite dry, gold or silver leaf is laid on, and the whole then receives a finishing coat of the varnish.

Our method of japanning differs from this in certain particulars. For black japanned works, the ground is first prepared with a coating of black, consisting of drop ivory-black mixed with dark-coloured animè varnish. This coating is well dried in a stove, and then varnished three or four times, the work being well dried between each. If coloured grounds are required, one or two thick coats of colour mixed with varnish are first laid on, and several varnishings and dryings complete the work. The ordinary painter's colours, ground with linseed oil or turpentine, and mixed with animè varnish, enable the workers in japan goods to produce a variety of effects according to their taste and fancy. The articles may be black or brown with gilded edges, or they may imitate marble, fine-grained wood or tortoiseshell, the last named being produced by vermilion with a varnish of linseed oil and umber. The colours most in request for this kind of work are flake-white or white-lead, Prussian-blue, vermilion, Indian-red, king's-yellow, verdigris, and lamp-black, with numerous intermediate tints produced by their mixtures. The varnishes employed are copal, or a varnish composed of seed-lac, or of gums animè and mastic. The lac varnish is the best as it respects hardness, but is too high coloured to be used alone on the more delicate grounds: it is therefore mixed, for such purposes, with gum-varnish, or it is superseded by copal varnish. Copal or animè varnish made without driers is applied two or three times, or as many as five or six times to the best works, to protect and give brilliancy to the colours.

It frequently happens that the articles to be japanned are either too coarse and soft to receive the lacker, or their substance is not sufficiently smooth without priming and preparation. Perhaps every workman has his own favourite method of preparation, and of mixing his varnishes; but it must be remarked, that whatever the care employed, works executed on an artificially prepared ground can never be depended on for durability, being much more liable to crack than those which are lackered on the solid substance of the object itself. The priming is of size and chalk or whiting, mixed up to a proper consistence to be laid on with a brush. It should be left a day or two to dry, and then brought to a proper smoothness of surface by rubbing with rushes, and then by the application of a wet cloth. When thoroughly dry the grounds are laid on smoothly with a brush, and finished by varnishing and polishing with rotten stone, or if the ground be white with putty or starch and oil. A brilliant ground is sometimes formed by laying it entirely in gold. This is done by going over the work with japanner's gold size, and when this is nearly dry but still clammy, it is covered with gold dust, applied on a piece of wash-leather. This when highly varnished has a very splendid effect. Ladies' work-boxes, work-tables, &c., are frequently ornamented with engravings or drawings transferred to the japan work. For this purpose the engraving is printed, or the drawing made on fine paper which has been previously prepared with a coat of isinglass or gum water. This, when dry, is applied with its face downwards upon the japan ground, covered with a thin coat of copal varnish; the paper is then moistened on the back with a sponge dipped in warm water, which soon dissolves the isinglass or gum, and the paper being loosened can then be taken away, leaving the print on the work. Or a print may be executed on an elastic composition of glue, &c., which receives the impression as well as paper, and may be immediately laid down upon the japanned surface, which will thus receive a perfect impression. All the processes connected with japanning require so much drying between them, that it is very desirable to hasten the work by means of stoves.

Common articles of furniture, such as dressing-tables, chairs, washstands, &c. are frequently said to be japanned, implying a greater durability than ordinary wood-painting; but the chief difference seems to be that the colours employed in painting them have been mixed with turpentine instead of oil.

JASPER. A handsome stone for inlaid work, which admits of a high polish, but is not used as a gem. It is a siliceous rock, containing, according to Beudant, silica 93·57 per cent., peroxide of iron 3·98, alumina 0·31, lime 1·05, water 1·09. It is coloured red by the peroxide, and yellow or brown by the hydrate of iron. It also occurs of green and other shades. When striped with green, yellow, red, or brown, it is called *riband jasper*. When these colours are in irregular concentric zones, it is called *Egyptian jasper*. Another variety is called *ruin jasper*, when a variety of brown markings appear on a dark ground. Jasper is nearly equal to agate in point of hardness, and is subject to the same treatment as carnelian in the lapidary's art.

JET. A variety of bituminous mineral coal, harder than cannel coal, of a deeper black colour, and possessing a higher lustre. It receives a brilliant polish, and is worked in the same manner as alabaster. In jewellery, the use of jet in mourning ornaments is very considerable. Jet is found at Whitby, Scarborough, and Yarmouth, and is also imported from Turkey. It can be turned with most of the ordinary tools, and worked with files and saws. Before the polishing, it appears of a brown colour, but after that process, it attains a beautiful and brilliant black. See COAL.

JET D'EAU. See ARTESIAN SPRINGS.

JEWELLING OF WATCHES. The frame-plates and other parts of watches are perforated by the watch-finisher, or escapement-maker, for the watch-jeweller, whose business it is to fit into the holes thus made certain hard stones, such as rubies, sapphires, chrysolites, and in some cases, diamonds, so perforated that the pivots of the watch movement may work in them. Diamonds are chiefly prepared in Holland, but all other hard stones are ground, polished, turned, drilled, and set by the watch-jeweller. Diamond powder (*bort*), embedded in small copper disks or mills, is the material used for grinding and polishing; and a fragment of bort set in a handle (as explained under CARBON, where different forms of diamond tools are figured,) is used for turning and drilling. A steel tool with diamond powder and oil is also used for drilling. Rapid motion is given by a lathe, with a large foot-wheel, so as to give the mandril from 6,000 or 7,000 up to 20,000 revolutions per minute, the latter speed being given for polishing only. The stone is ground by taking it on the end of one of the fingers of the right hand, and applying it to the surface of the bort mill, which is kept constantly wet with water applied by the fingers of the left hand: in a few seconds a flat surface is produced on a stone of the most irregular form; the flat surface is then placed next the finger, and a similar surface is produced parallel to the former, until the stone is of the thickness required: it is then placed, by means of cement, on a small chuck in the lathe, and turned with a bort tool into the proper shape for setting: the hole is then drilled, first, about half way through, when the stone is reversed, and the drilling completed from the opposite side; a precaution necessary to prevent fracture. The hole is also turned with a countersink, to receive the oil required for the lubrication of the pivot. The polishing is performed by hollowing out one end of a piece of brass, so as to fit the hollow of the stone, and with diamond powder therein, working it about in every possible direction, by pressing the finger against the other end of the brass. The stone is then detached from the lathe, and its flat surfaces polished by the rapid motion of the hand on a piece of plate-glass charged with diamond powder and oil.

Stones may be perforated so that the shoulder of the axis be supported by them; or in such a way, that the axis may pass completely through them, in which case an *end-piece* is required for supporting the end of the pivot. The latter method is adopted where the pivot is in rapid motion, and has a considerable weight to sustain, as in the case of the pivots at each end of the axis of the balance.

Fig. 1259 is a section, on an enlarged scale, of the jewelled pivot-hole for the axis of the balance of a chronometer. *a* is the hardened steel pivot, which is turned with a fine cylindrical neck, and made convex at the end. *b* is the drilled jewel, and above it, the end-piece. *b* is turned convex above, and concave beneath, of two different sweeps, to make it very thin at the point where it is drilled, and it is made a little smaller in the middle, to lessen the surface bearing. The end-stone is in the form of a plano-convex lens: it is generally a ruby, but in some cases, a diamond, cut into facets. The very small distance between the two stones allows the oil to be retained by capillary attraction. Each stone is burnished into a brass or

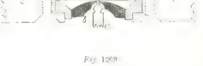

Fig. 1259

steel ring, in a manner similar to that in which glasses are set in telescopes, by turning a place to receive the stone, and leaving a fine edge of brass, which is rubbed over the edge of the stone with a burnisher. A diamond end-piece is usually set in steel, into which it is brazed; after which, the steel is turned into shape, polished, and blued. The stones are inlaid in a counter sunk recess, *c d*, in the side plate, or other part of the watch, and retained therein by two side screws, as shown in the figure.

The jewelling of watches is very minute and delicate work, as will be understood from the statement of the dimensions of the parts of Fig. 1259: the side plate *e e* is $\frac{1}{10}$ inch in thickness: the rings from *c* to *d* $\frac{1}{8}$ inch in diameter, and the pivot $\frac{1}{100}$ inch in diameter. In some of the flat Geneva watches, these dimensions are greatly reduced.

JOINERY. See CARPENTRY.

JOISTS. See CARPENTRY.

JOURNALS. See GUDGEONS.

KALI. The name of a maritime plant, the ashes of which furnish soda. From the name of this plant, with the Arabic article *al*, is derived the name of a class of substances of great importance in the arts. [See ALKALI.] The term kali was formerly applied to the alkali potash, the chemical symbol of which, K, is the initial letter of kalium.

KAOLIN. See CLAY, also POTTERY and PORCELAIN, and APPENDIX.

KELP. The ash remaining after burning sea-weed, for the purpose of obtaining carbonate of soda from it. See SODIUM, IODINE.

KERMES. Two substances of totally different properties are known by this name; the one, *kermes mineral*, is the golden sulphuret of antimony, [see ANTIMONY,] the other, *kermes grains*, a red dye stuff, consisting of the dried bodies of the female insects of the species *coccus ilicis*, and found upon the leaves of the *quercus ilex*, or prickly oak. The word *kermes* signifies in Arabic *little worm*; hence, this dye was called *vermiculus* in Latin, and *vermilion* in French, a term now applied to the red sulphuret of mercury. Kermes was formerly known as *German cochineal.* The rural serfs of Germany were bound to deliver every year to the convents, a certain quantity of kermes: it was collected from the trees upon St. John's day, between 11 o'clock and noon, with certain religious ceremonies, and was hence called *Johannisblut*, or St. John's blood. After the discovery of America, cochineal gradually superseded kermes for all brilliant red dyes. Lac dye is also an advantageous substitute; but at the present day, the Turks, Armenians, and Cossacks dye with kermes their morocco leather, cloth, silk, horse hair, &c. The red caps of the Levant are dyed with equal parts kermes and madder. Scarlet and crimson dyed with kermes were called *grain colours*, and were supposed to be more durable than cochineal colours, as the old Brussels tapestry may show.

The colouring matter of kermes is soluble in water and alcohol: it becomes yellowish or brownish with acids, and violet or crimson with alkalis. Sulphate of iron blackens it; it dyes a blood red with alum; an agate grey with copperas; with copperas and tartar a lively grey; with sulphate of copper and tartar a lively green; with tartar and salt of tin a lively cinnamon yellow; with a larger proportion of alum and tartar a lilac; with sulphate of zinc and tartar a violet.

Kermes should be plump, of a deep red colour, with an agreeable smell, and a rough pungent taste.

KERSEYMERE. See WOOL.

KILLAS. The clay-slate in which copper ores, &c., occur.

KILN, a name applied to various forms of close furnaces, differently arranged according to the purposes for which they are intended. Different kilns are described under BRICK, LIMESTONE, POTTERY, &c. A *malt kiln* is described under BEER; and it has been supposed that the operation of *killing* or *quelling* the vegetation of the moistened barley by heat, has given the name of *kill* or *kiln* to the hot chamber in which it was performed, and hence also to other enclosed heated places.

KING'S YELLOW, a pigment, the basis of which is orpiment or yellow sulphuret of arsenic (AsS_3). See ARSENIC.

KINIC ACID, an acid contained in the different species of cinchona or Peruvian barks, in combination with lime. It is also named *cinchonic* or *quinic* acid. Kinate of lime is found in the solution from which the bark alkalis have been separated, and the acid is extracted by decomposing the lime salt by dilute sulphuric acid. The clear solution, on being evaporated, deposits large distinct crystals of kinic acid, which resemble those of tartaric acid. Kinic acid is soluble in 2 parts water, and contains $C_{14}H_{11}O_{11}$, HO.

When kinic acid is treated with sulphuric acid and peroxide of manganese, it furnishes a very volatile substance, termed *chinone*, the vapour of which is very irritating to the eyes. It contains $C_{25}H_8O_8$. The odour of chinone is so distinct, that it enables us to detect the presence of kinic acid, and thus serves as a means of distinguishing true from spurious barks. According to Stenhouse, "to examine a bark for kinic acid, all that is necessary is to boil a little of it with slight excess of lime, to pour off and concentrate the liquor, introduce it into a retort, and distil it with a mixture of half its weight of sulphuric acid, and of peroxide of manganese. If the bark contain the smallest quantity of kinic acid, the first portion of the liquor which distils over has a yellow colour, and the very peculiar smell of chinone." Less than $\frac{1}{4}$ ounce of bark is sufficient for the experiment: the distillation need not be continued long, on account of the great volatility of the chinone. Two ounces of false bark (*China nova Surinamensis*), treated in this way, gave no indications of kinic acid.[1]

KINO, an extractive matter, the concrete juice of one or more plants growing in the East and West Indies, Africa, New Holland, &c. It is of a reddish brown colour, has a bitter styptic taste, and consists chiefly of tannine.

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(1) "Memoirs of the Chemical Society," vol. ii.

KNIVES. See CUTLERY.

KREOSOTE, (from κρέας, flesh, and σώζω, I preserve.) This interesting product is obtained by distilling wood-tar. It is remarkable for its antiseptic power. A piece of flesh steeped in a very dilute solution, dries up, but does not putrefy. The great efficacy of impure wood vinegar in preserving provisions, is due to the kreosote contained in it, and the effect of wood smoke in curing and preserving salted meat and other provisions, is due to the same cause.

Kreosote exists abundantly in the heavy oil of beech-tar, as supplied by the wood-vinegar maker, and is procured therefrom by a tedious series of operations, which are described by Dumas in the 5th vol. of his "Chimie appliquée, &c." The distillation is conducted in a metallic vessel, and the different products collected apart. The most volatile portion, which is lighter than water, is rejected, but the second and denser portion, containing the kreosote, is agitated with carbonate of potash, to remove any adhering acid. This denser portion is then separated, and redistilled. The first portion that comes over is again rejected. It is then briskly agitated with a solution of phosphoric acid, and again distilled, whereby ammonia is separated. It is next dissolved in a solution of caustic potash of specific gravity 1·12, and decanted from the insoluble oil which floats on the surface. This alkaline liquid is boiled, and left some time in contact with the air, by which it acquires a brown colour. Sulphuric acid is next added to separate the alkali. The kreosote is again dissolved in caustic potash, boiled in the air, and the solution decomposed by acid, and this treatment is repeated until the product ceases to be coloured by exposure to air, and to the alkali. Much of the kreosote of commerce, however, turns brown by exposure, showing that it is not quite pure. It is, lastly, well washed with water, and distilled from a little hydrate of potash. The first portion that comes over contains water: the after product is pure kreosote. In this condition it is a colourless, somewhat viscid, oily liquid, of great refractive and dispersive power. It has a penetrating peculiar odour, resembling that of smoked meat. It is most painfully pungent when applied to the tongue in small quantities. Its density is 1·037; its boiling point 397° Fahr. It is not readily ignited, and it burns with a smoky light. When mixed with cold water two solutions result, one consisting of 1·25 kreosote + 100 water; the other of 100 kreosote + 10 water. The aqueous solution is neither acid nor alkaline. Hot water dissolves a little more kreosote than cold, but the excess is again liberated on cooling. Kreosote absorbs moisture from the air. It dissolves readily in acetic acid; alcohol and ether mix with it in all proportions. Caustic potash dissolves in it, forming a crystalline pearly compound. It dissolves the resins, camphor, the essential oils, and most colouring matters. It immediately coagulates egg albumen, although much diluted.

Mr. Fitch has patented a process for impregnating salt with the more volatile products of wood-tar. The salt thus prepared is doubly preservative, and meat to which it is applied, is at once smoked and salted. Tongues and hams may be effectually cured by immersing them for 24 hours in a mixture of 1 part pure kreosote, and 100 parts of water or brine: the resulting flavour is said to be very delicate. Kreosote is medicinally employed in toothache, for dressing ulcers, and for external application in cutaneous diseases. It is also used to check hæmorrhage, and internally as a stimulant, and for the prevention of nausea and vomiting. It also prevents mouldiness in ink.

The composition of kreosote is not yet settled. That met with in commerce is simply carbolic or phenic acid, $C_{12} H_6 O_2$. The confusion respecting kreosote seems to arise from the uncertain nature of the products produced by the distillation of wood. The kreosote obtained from coal is said to contain two distinct homologous bodies. *Carbolic* and *Cresylic* acids, $C_{12} H_6 O_2$ and $C_{14} H_8 O_2$. Common coal kreosote sometimes contains only cresylic acid. Carbolic acid boils between 369° and 370°. Cresylic acid boils at 397°. If kreosote be found quite soluble in potash and acetic acid of the density 1·070, and does not become coloured by exposure to the air, it may be regarded as pure enough for medicinal purposes.

END OF VOL. I.

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